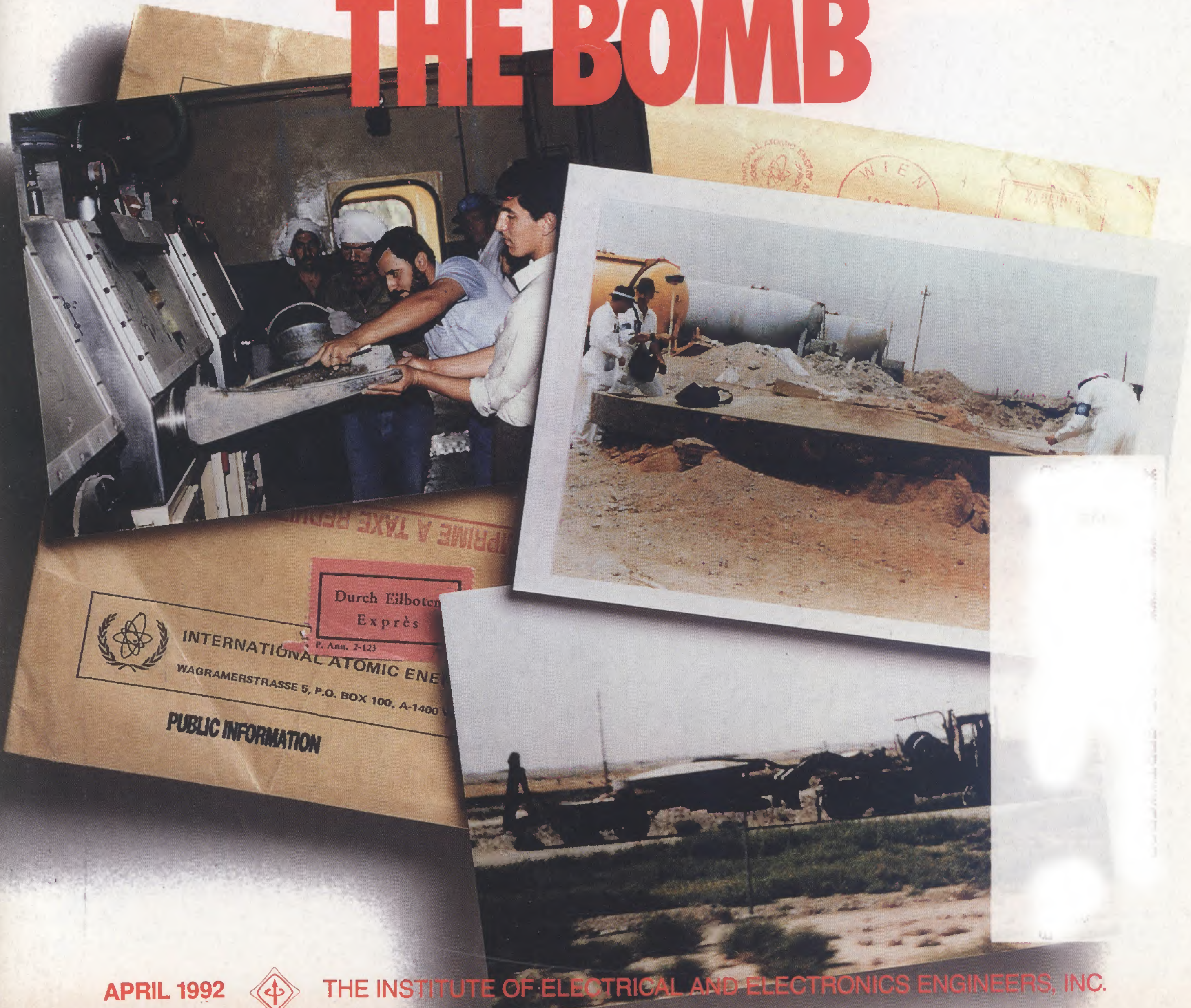
SPECIAL **WORKSTATIONS** GUIDE P. 25

IEEE

SPECTRUM

HOW IRAQ REVERSE-ENGINEERED THE BOMB



APRIL 1992 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

Newslog

FEB 16. National Engineers Week opened with a two-hour nationwide teleconference, "Discover Engineering," via satellite. Transmitted from the **Massachusetts Institute of Technology** campus in Cambridge to over 375 U.S. sites, it was viewed by 8000 college and precollege students.

FEB 18. LSI Logic Corp., Milpitas, Calif., said it had developed a technology—CoreWare—that can combine a microprocessor core on a single chip with other circuits specified by a customer. Similar chips are now offered by others, but give buyers little say in what additional circuits are printed on it.

FEB 20. Researchers for **General Electric Co.,** Fairfield, Conn., said they had produced a 52-W beam of green light—double the power of green beams previously produced—from an infrared beam generated by a solid-state laser.

FEB 21. Russian space officials told a U.S. Senate subcommittee they had offered the United States use of their six-year-old **Mir space station** as an international laboratory. They also offered their Soyuz spacecraft as an emergency crew-rescue vehicle for the proposed U.S. space station Freedom.

FEB 24. Apple Computer Inc., Cupertino, Calif., said it had developed a Macintosh model that responds to spoken commands using continuous speech. Current speech-recognizers for PCs work well only when speakers say one word at a time, pausing after each word.

FEB 26. The 10 New England utilities that own **Yankee Rowe,** Rowe, Mass., the oldest U.S. nuclear power plant, said they would permanently close the 32-year-old reactor, which had been shut since September for safety tests. The owners blamed the shutdown on the high cost of determining whether the plant was safe to run. The electric utility industry had hoped the reactor would prove that nuclear power plants could operate safely for 60 years.

FEB 26. United Telecommunications Inc., Kansas City, Mo., said it had changed its name to **Sprint Corp.** The company includes U S Sprint, the third-largest long-distance U.S. carrier, seven local telephone groups serving 4 million subscribers in 17 states, and a telephone directory publishing unit.

FEB 26. Hewlett-Packard Co., Palo Alto, Calif., said it would collaborate with **TV Answer Inc.,** a developer of wireless data services in Reston, Va., on the first national interactive television system. In January, the Federal Communications Commission, Washington, D.C., responding to a 1987 petition by TV Answer, had allotted a little of the radio spectrum to interactive TV. HP will make a $700 TV control box and remote controller, while TV Answer will link interactive licensees into a network of stations.

FEB 29. The **Long Island Lighting Co. (Lilco),** Garden City, L.I., said it had signed over the ownership of its $5.5 billion Shoreham nuclear power plant to the **Long Island Power Authority,** which will dismantle it. Under a settlement between New York State and Lilco, the Power Authority will receive $1 for the 809-MW reactor, and Lilco will get annual rate increases of about 5 percent for 10 years to restore it to financial health. The transaction, which came only hours after the U.S. **Nuclear Regulatory Commission** gave final approval to the transfer, ended a 25-year battle over whether the plant would be allowed to operate.

MAR 2. U.S. delegates attending the **World Administrative Radio Conference** in Torremolinos, Spain, said that more than 120 governments had agreed on a treaty that would allocate global radio frequencies of 1610–1626.5 MHz for fleets of low-orbiting satellites serving portable telephone and message services.

MAR 3. ITT Corp., New York City, said it would sell its 30 percent stake in **Alcatel NV** of the Netherlands to **Alcatel Alsthom SA,** its French partner in a telecommunications equipment venture, for $3.6 billion. The move ended ITT's longstanding involvement in the telephone equipment industry, its original business.

MAR 3. AT&T Co. said it will introduce voice recognition call processing, a technology that could replace up to one-third of its 18 000 long-distance operators by 1994.

MAR 4. Cox Enterprises Inc., Atlanta, Ga., and **Tele-Communications Inc.,** Denver, Colo., two of the largest U.S. cable television companies, said they had joined in purchasing **Teleport Communications Group Inc.,** a small corporate telephone services company in New York City, from Merrill Lynch & Co.

MAR 4. Fujitsu Ltd., Tokyo, the world's second largest supercomputer maker after Eagan, Minn.-based **Cray Research Inc.,** announced it would reenter the U.S. supercomputer market after a three-year absence by marketing its VP2000 supercomputer line primarily to private industry.

MAR 5. U.S. administration officials said it had reached an agreement with Europe and Japan to loosen international controls on exports of advanced telecommunications equipment—including high-quality optical-fiber cables. The pact represents a basic shift in U.S. policy toward the former Soviet republics and could lay a base for U.S. business there.

MAR 6. The **Federal government** said it would hire over 100 scientists from Russia to help the United States harness nuclear fusion. The deal—which calls for research to be done at the Kurchatov Institute of Atomic Energy in Moscow—is the first in which the U.S. government has tapped Russia's scientific talent. Days earlier, private industry—through **Sun Microsystems Inc.,** Mountain View, Calif.—said it had hired 50 software and hardware designers from the former Soviet space program to help Sun improve computational abilities of its microprocessors.

MAR 6. Computer experts said the **Michelangelo computer virus** came to life as scheduled, but from all reports the infection caused barely a sneeze among the millions of PCs worldwide. The worst effects reported by national press agencies appear to have been in South Africa, where about 750 PCs used by the nation's pharmacists were struck; Uruguay, where it upset the Army's intelligence information system; and Argentina, where Viedma's daily newspaper *Bariloche* had its computer records destroyed.

MAR 9. China Light & Power Co., Hong Kong, and its partner **Exxon Corp.,** Irving, Texas, said they would spend up to $7.8 billion over the next decade on new power plants and associated transmission and distribution systems in Hong Kong.

Preview:
APR 22. Earth Day 1992 is to focus attention on renewable energy and improved energy efficiency issues that could help combat global warming, acid rain, and radioactive waste. Contact Public Citizen, Washington, D.C.; 202-546-4996.

COORDINATOR: Sally Cahur

APRIL 1992 Volume 29 Number 4

IEEE SPECTRUM

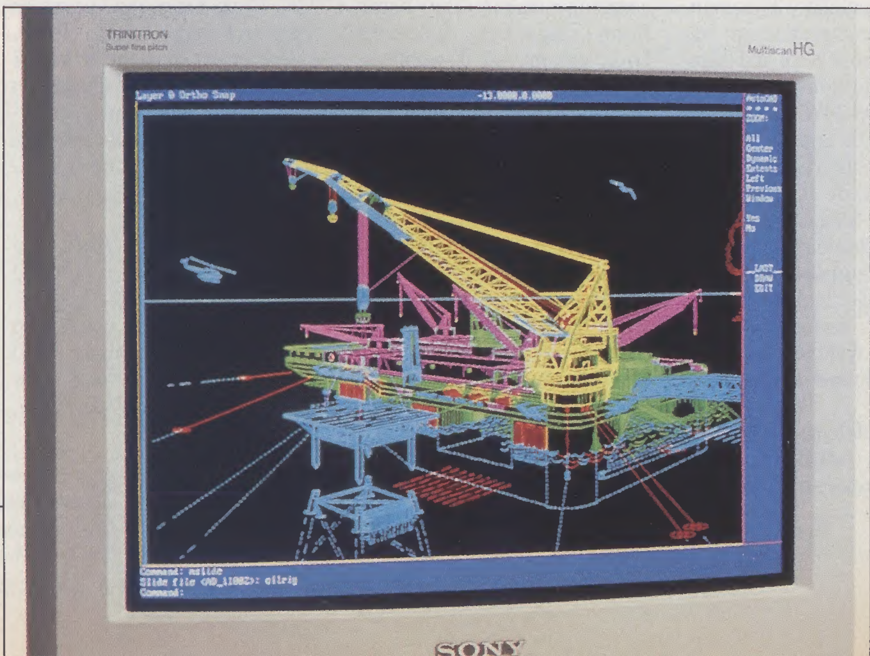
SPECIAL REPORT

SEEKING NUCLEAR SAFEGUARDS

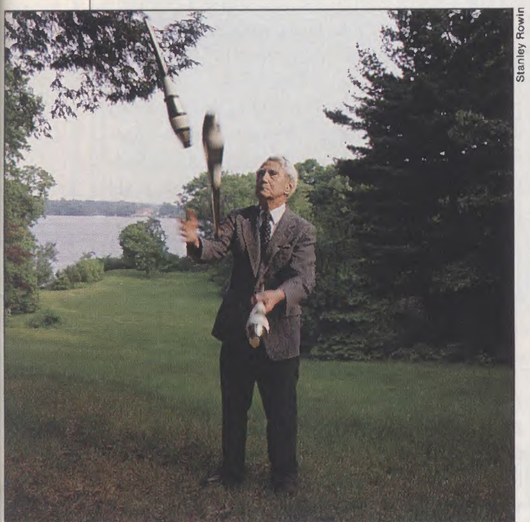
Vadim Mouchkin/International Atomic Energy Agency

FOCUS REPORT

ENGINEERING WORKSTATIONS



Sony Corp. of America



Stanley Rowin

Cover: International Atomic Energy Agency (IAEA) personnel discover and dismantle key components of the Iraqi nuclear program. The photos were provided to *IEEE Spectrum* by the IAEA and are described more fully on p. 21.

IEEE SPECTRUM (ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc.

345 East 47th St., New York, N.Y. 10017, U.S.A. Cable address: ITRIPLEE. Telex 236-411. Telecopier: 212-705-7453. *ANNUAL SUBSCRIPTIONS.* IEEE members: $10.00 included in dues. Nonmembers: $29.95. Libraries/institutions: $119. *SINGLE COPIES.* Members: $8 first copy, $16 per additional copy. Nonmembers: $16. *MICROFICHE SUBSCRIPTIONS.* Members: $16. Nonmembers and libraries: $119. *POSTMASTER:* Please send address changes to *IEEE Spectrum*, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855. Second Class postage paid at New York, N.Y., and additional mailing offices. Canadian GST #125634188.

Printed at 8649 Hacks Cross Rd., Olive Branch, Miss. 38654.

IEEE Spectrum is a member of the Audit Bureau of Circulations, the Magazine Publishers of America, and the Society of National Association Publications.

Staff

EDITOR AND PUBLISHER: Donald Christiansen

EXECUTIVE EDITOR: Edward A. Torrero

MANAGING EDITOR: Alfred Rosenblatt

SENIOR TECHNICAL EDITOR: Gadi Kaplan

SENIOR EDITORS: Trudy E. Bell, Richard Comerford, Tekla S. Perry, Michael J. Riezenman, George F. Watson

SENIOR ASSOCIATE EDITORS: John A. Adam, Glenn Zorpette

HEADQUARTERS: New York City 212-705-7555
BUREAUS: WASHINGTON, D.C., John A. Adam, 202-544-3790; *SAN FRANCISCO*, Tekla S. Perry, 415-282-3608

CORRESPONDENTS: Fred Guterl, Roger Milne (London); Bradford Smith (Paris); John Blau (Düsseldorf); Robert Ingersoll (Bonn); John Mason (Barcelona); Stuart M. Dambrot, Roger Schreffler (Tokyo); Kim Nak-Hieon (Seoul); Chris Brown (Taipei); Peter Gwynne (Hong Kong); Tony Healy (Sydney, Australia); Christopher Trump (Toronto); Axel de Tristan (Rio de Janeiro); Kevin L. Self (Houston)

CHIEF COPY EDITOR: Margaret Eastman
COPY EDITOR: Sally Cahur
EDITORIAL RESEARCHER: Alan Gardner

CONTRIBUTING EDITORS: Karl Esch, Ronald K. Jurgen, Michael F. Wolff

EDITORIAL INTERNS: George Likourezos, Dana Norvila

EDITORIAL SUPPORT SERVICES: Rita Holland (Manager)
EDITORIAL ASSISTANTS: Ramona Foster, Desiree Noel

DESIGN CONSULTANT: Gus Sauter

OPERATIONS DIRECTOR: Fran Zappulla
BUSINESS MANAGER: Robert T. Ross

EDITORIAL PRODUCTION:
Carol L. White (Director)
Marcia Meyers (Manager)
Peter Ruffett (Typographer)
Morris Khan (Technical Graphic Artist)

ASSOCIATE PUBLISHER: William R. Saunders
ADMINISTRATIVE ASSISTANT: Carmen Cruz
MAIL LIST SALES: Shelly Newman (Manager), Lizette Graciani
ADVERTISING PRODUCTION:
Theresa Fitzpatrick (Manager), Francesca Silvestri

MARKETING DIRECTOR: Arthur C. Nigro
PROMOTION MANAGER: Robert D. Moran
RESEARCH MANAGER: Hendrik Prins
MARKETING SERVICES: Eric Sonntag (Administrator)

ADMINISTRATIVE ASSISTANT TO THE EDITOR AND PUBLISHER: Nancy T. Hantman

Forum

Software needs more of a hardware attitude

As a software engineer and chairman of the IEEE Computer Society, Boston Section, I find it inspiring that people in the IEEE are so focused on the continuing growth of performance in hardware. If only that same thinking could be applied in software, imagine how marvelous the combined results!

We in software, I am afraid, are more in the habit of repeating stock phrases like mantras, rather than rolling up our sleeves and investigating things.

In the area of performance, one often-repeated phrase is [the computer science guru] Donald Knuth's observation that "Less than 4 percent of a program generally accounts for more than half of its running time." The truth of this statement is seldom questioned, but it implies a particular myth of computation: that a piece of software is a homogeneous finite-state machine.

In industrial-grade software, the time-average depth of the call stack can be 10 levels, making the state space intensely hierarchical. Truly massive speedup can be had by reducing the number of mid-level subroutine calls. How to find them?

People who do this for a living use a very simple technique: randomly halting the program and observing the call stack, and maybe single-stepping it a little bit. Typically, some innocuous one-line subroutine call turns up on the stack a large fraction of the time, and checking the source code shows it to be easily coded around. Doing so eliminates that fraction of the total run time. Repeating this process several times can turn almost any software from a dog into a rocket. But . . . there must be a desire to investigate.

(Distributed systems are a little more difficult, but the idea is the same. The question is "What is it doing, and why?")

This is just one example of how the vigorous inventive enthusiasm of electronic engineers might be passed on to your software brethren. There are other areas where we could use some of this spirit.

For example, in software productivity, an oft-repeated mantra is that re-using software reduces the life-cycle cost of system development. However, if this principle is applied uncritically, are we not risking the consequences of the proverbial "K-Mart special," where the more we buy, the more we save? It would take a true engineer to say that the real objective is to reduce cost, not to use a particular method.

We in software are spoiled. We do not have to worry about fanout, glitches, crosstalk, or heat. We have lost touch with humbling reality, and I am afraid it shows. Help us!

Michael Dunlavey
Needham, Mass.

A different standard

The review by D. Richard Kuhn of the Posix project [December, pp. 36–39] was, on the whole, a welcome contribution to improved understanding of portability issues and open system goals. However, I was disappointed to see no mention of the MOSI [Microprocessor Operating Systems Interfaces] standard, IEEE 855.

MOSI is not a part of Posix [Portable Operating Systems for Computer Environments], but it makes a significant contribution to open system goals. Like Posix 1003.1, MOSI defines a system API [application programmer interface]. It is the only API specification besides 1003.1 that is already a fully approved IEEE standard.

Despite its similar domain, MOSI complements Posix rather than competing with it. The 1003.1 standard provides a detailed specification for the most important services provided by systems whose API is based strongly on the Unix model. It is designed to complement the facilities of ANSI C.

MOSI is less detailed but broader-based. It defines a service interface that can be implemented in Unix (or Posix) environments, and also in very different environments. This interface is leaner and completely specified, but it can facilitate porting applications across a very wide range of environments.

Further, MOSI does not assume a specific programming language, but is defined in a language-independent way. Recommended language bindings for several languages are given in the MOSI appendices.

MOSI was approved as an IEEE "Trial-use" standard in 1985, and a substantially revised version was approved as a full standard in 1990. Presently it also has the status of a Draft International Standard (DIS 11685.2) and is undergoing balloting for final ISO/IEC approval in JTC1/SC26.

James D. Mooney
Morgantown, W.Va.

Credit where it's due

It interests me that "Innovative Genius" perpetuates the myth that Arthur C. Clarke "invented" the communications satellite. The fact is that communications satellites were first described by George O. Smith in his novel *Venus Equilateral*, published in 1947.

Regarding John R. Pierce's contribution, he was involved in the design of AT&T Co.'s Telstar experiment.

Beardsley Graham
Baker City, Ore.

IEEE Spectrum's special report purports to answer the questions "Innovative genius: What is it? Who has it?" by profiling eight innovators [December, pp. 22–35]. I thought some of Michael Maccoby's analyses were insightful and the profiled individuals certainly are innovative. However, some assumptions in both Maccoby's analysis and *Spectrum*'s selections need explanation.

I do not consider myself an equal rights spokesperson, but I was frankly surprised by the lack of ethnic, racial, and gender balance in the profiles. How was the criterion of "a spectrum of backgrounds" applied?

Maccoby states, "Doubtless, genetics plays a major role, and so it would seem from their family histories." However, other factors, such as living in a culturally and intellectually enriched environment, deserve as much credit as genetics.

What message does the article send to "engineers just starting their careers" who are neither white U.S. nor Japanese males?

Thomas R. Potavin
Hopewell, N.J.

As a new member of the IEEE, I am appalled and dismayed. I am a female software engineer and realize that, in general, the number of men in the engineering field outweighs women. However, I find the IEEE's decision to choose only men as noteworthy to be sexist. I have considered joining the Society of Women Engineers, but I had decided to try the IEEE. Now I see why a society like the SWE is necessary.

Obviously, the purpose of the article is to inspire and show how some top engineers got where they have. I can be inspired by people of many different backgrounds; the IEEE has failed to include those people.

Diane Harvey
Santa Clara, Calif.

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate on controversial issues. Contacts: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017, U.S.A.; fax, 212-705-7453. The Compmail address is ieeespectrum.

Calendar

Meetings, Conferences and Conventions

APRIL

Southeastcon '92 (Region 3 et al.); April 12–15; Wynfrey Hotel, Birmingham, Ala.; Wayne Owen, South Central Bell, 600 N. 19th St., Birmingham, Ala. 35203; 205-321-2299.

Intermag '92 (MAG); April 13–16; Adams Mark Hotel, St. Louis, Mo.; Courtesy Associates Inc., 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-639-5088.

International Conference on Computer Languages (C); April 20–23; Cathedral Hill Hotel, San Francisco; IEEE Computer Society, Conference Dept., 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013.

Fourth International Conference on Indium Phosphide and Related Materials (ED); April 21–24; Newport Sheraton, Newport, R.I.; Susan Evans, IEEE/LEOS Executive Office, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3896.

Seventh Conference on Semi-Insulating III-V Materials (ED); April 21–24; Krystal Hotel, Ixtapa, Mexico; William Ford, Harris Microwave Semiconductor, 1530 McCarthy Blvd., Milpitas, Calif. 95035; 408-433-2222.

Electrical Performance of Electronic Packaging (CHMT, MTT); April 22–24; Holiday Inn, Tucson, Ariz.; Paul Baltes, Engineering Professional Development; Harvil Building, Box 9, University of Arizona, Tucson, Ariz. 85721; 602-621-5104; fax, 602-621-1441.

Workshop on Workstation Operating Systems—WWOS-III (C); April 23–24; Sheraton Royal Biscayne, Key Biscayne, Fla.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

Scalable High Performance Computing Conference (C); April 26–29; Williamsburg Hilton and National Conference Center, Williamsburg, Va.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7305.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

Calendar

(Continued from p. 8)

Third Winlab Workshop on Third Generation Wireless Information Networks (VT); April 28–29; Ramada Renaissance Hotel, East Brunswick, N.J.; Melissa Gelfman, Winlab, Rutgers University, Piscataway, N.J. 08855-0909; 908-932-0283.

MAY

Custom Integrated Circuits Conference—CICC '92 (ED); May 3–6; Westin Copley, Boston; Laura Morihara, Convention Coordinating, 47-344 Waihee Rd., Kaneohe, Oahu, Hawaii 96744; 808-239-4790.

Industrial and Commercial Power Systems Technical Conference (IA et al.); May 4–7; Sheraton-Station Square Hotel, Pittsburgh; Dave Shipp, Westinghouse Corp., 750 Trumbull Dr., Pittsburgh, Pa. 15205; 412-429-7430.

International Conference on Computer Systems and Software Engineering—Compeuro '92 (C, Region 8, et al.); May 4–7; Netherlands Congress Center, the Hague; P.M. Dewilde, Delft University of Technology, Department of Electrical Engineering, Mekelweg 4, 2628 CD Delft, The Netherlands; (31+15) 7850 89.

Infocom '92 (C, COM); May 4–8; Congress Center, Florence, Italy; Maurizio Decina, Consorzio Cefriel, Viale Sarca 202, 20126 Milan, Italy; (39+2) 661 00083.

Second Annual Pacific Northwest Test Workshop (C); May 5–8; Whistler Resort, Vancouver, B.C., Canada; Andre Ivanov, 604-822-6936, or Mani Soma, 206-685-3810; fax, 206-543-3842.

Project Management '92 (EM, ASCE/PMI, Chicago Section); May 7–8; Drake Hotel, Chicago; Project Management '92, 2460 Wisconsin Ave., Downers Grove, Ill. 60515; 708-963-4002.

Fifth IEEE Workshop on Metropolitan Area Networks (COM); May 10–13; Hotel Capo Taormina, Taormina, Italy; Luciano Lenzini, CNUCE, 36 Via S. Maria, 56100 Pisa, Italy; (39+50) 593 245.

International Symposium on Circuits and Systems—Iscas '92 (CAS); May 10–13; Sheraton Harbor Island Hotel, San Diego, Calif.; Stanley A. White, 433 E. Avenida Cordoba, San Clemente, Calif. 92672; 714-498-5519.

Conference on Lasers and Electro-Optics/Quantum Electronics Laser Sciences—CLEO/QELS '92 (LEO); May 10–15; Anaheim Convention Center, Anaheim, Calif.; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3893.

International Conference on Robotics and Automation (RA); May 10–15; Acropolis Convention Center, Nice, France; Harry Hayman, Box 3216, Silver Spring, Md. 20918; 301-236-5621; fax, same number; 301-236-5621 after March 31.

Microwave Power Tube Conference (ED); May 11–13; Naval Postgraduate School, Monterey, Calif.; Ralph Nadell, Palisades Institute, 201 Varick St., New York, N.Y. 10014; 212-620-3341; fax, 212-620-3379.

Vehicular Technology Conference (VT, Denver Section); May 11–13; Regency Hyatt Hotel, Denver, Colo.; Jim Schroeder, Department of Engineering, University of Denver, 2390 S. York St., Denver, Colo. 80208-0177; 303-871-3519.

Electro '92 (Region 1 et al.); May 12–14;

Calendar

Hynes Convention Center, Boston; Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, Calif. 90045; 213-215-3976; fax, 800-877-2668.

Instrumentation and Measurement Technology Conference (IM et al.); May 12–14; Meadowlands Hilton Hotel, Secaucus, N.J.; Robert Myers, 3685 Motor Ave., Suite 240, Los Angeles, Calif. 90034; 213-287-1463; fax, 213-287-1851.

International Symposium on Semiconductor Manufacturing Technology—ISSMT '92 (ED); May 14–15; The Hotel New, Otani, Japan; Tadahiro Ohmi, Department of Electronics, Tohoku University, ASA-Aoba, Aramaki, Sendai 980, Japan; fax, (081+022) 224 2549.

Symposium on Worldwide Advances in Communication Networks (COM); May 14–15; George Mason University, Fairfax, Va.; Telecommunications Laboratory, ECE Department, George Mason University, Fairfax, Va. 22030-4444; 703-993-1566; fax, 703-993-1521.

42nd Electronic Components and Technology Conference (CHMT); May 18–20; Sheraton Harbor Island Hotel, San Diego, Calif.; Peter J. Walsh, Electronic Industries Association, 2001 Pennsylvania Ave., N.W., Washington, D.C. 20006-1903; 202-457-4932.

Conference on European Electrotechnology in a Worldwide Market—Eurocon '92 (COM, Region 8); May 18–21; Congress Centre, Zurich; A. Kundig, TIK, ETH-Zentrum, ETZ G 84, CH-8092, Zurich, Switzerland.

National Aerospace and Electronics Conference (AES, Dayton Section); May 18–22; Dayton Convention Center, Dayton, Ohio; Sue Brown, ASD/ENES, Wright-Patterson Air Force Base, Ohio 45433-6503; 513-255-6281.

National Telesystems Conference (AES, NCAC); May 19–20; George Washington University, Ashburn, Va.; Talbot S. Huff Jr. or Sally Spooner, E-Systems Inc., Melpar Division, 7700 Arlington Blvd., Falls Church, Va. 22046; 703-849-1500.

Fourth International Symposium on Power Semiconductor Devices and ICs (IEE Japan, ED); May 19–21; Waseda University, International Conference Center, Shinijuki-ku, Tokyo; Hiromichi Ohashi, Electron Devices Laboratory, Toshiba R&D Center, 1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki, 210, Japan; (81+44) 549 2063; fax, (81+44) 555 2074.

International Geoscience and Remote Sensing Symposium (GRS); May 26–29; South Shore Harbour Resort and Conference Center, League City, Texas; Tammy I. Stein, HARC/STAR, 4800 Research Forest Dr., The Woodlands, Texas 77381; 713-363-7922.

36th International Symposium on Electron, Ion, and Photon Beams (ED); May 26–29; Peabody Hotel, Orlando, Fla.; Randy Kubena, Hughes Research Laboratories, 3011 Malibu Canyon Rd., Malibu, Calif. 90265; 310-317-5423; fax, 310-317-5840.

46th Annual Symposium on Frequency Control (UFFC); May 27–29; Hershey Lodge and Convention Center, Hershey, Pa.; Raymond L. Filler, U.S. Army ETDL, SLCET-EQ, Fort Monmouth, N.J. 07703-5601; 908-544-2467.

Workshop on Numerical Modeling of Processes and Devices For Integrated Circuits—Nupad IV (ED); May 31–June 1; Westin Hotel, Seattle, Wash.; Fely Barrera, Stanford University, 205 AEL Building, Stanford, Calif. 94305-4055; 415-723-4138; fax, 415-725-7298.

JUNE

19th International Conference on Plasma Sciences (NPS); June 1–3; Hyatt Regency Westshore Hotel, Tampa, Fla.; Norman L. Oleson, Department of Electrical Engineering, Eng 118, University of South Florida, Tampa, Fla. 33620; 813-974-2369; fax, 813-974-5250.

Symposium on Autonomous Underwater Vehicle Technology (OE); June 2–3; Dulles Airport Marriott Hotel, Washington, D.C.; Gordon Raisbeck, 40 Deering St., Portland, Me. 04101-2212; 207-773-6243.

International Microwave Symposium (MTT); June 2–4; Albuquerque Convention Center, Albuquerque, N.M.; Everett Farr, BDM Corp., 1801 Randolph Rd., S.E., Albuquerque, N.M. 87106; 505-848-5000.

VLSI Technology Symposium (ED); June 2–4; Westin Hotel, Seattle, Wash.; James Clemens, AT&T Bell Laboratories, 600 Mountain Ave., Murray Hill, N.J. 07974; 908-582-2800.

Second International Symposium on Atomic Layer Epitaxy (ED); June 3–5; Raleigh Marriott, Raleigh, N.C.; Salah M. Bedair, Department of Electrical Engineer-

(Continued on p. 8H)

NSF/IEEE CENTER ON Computer Applications in Electromagnetics Education (CAEME)

Request for Proposals

The NSF/IEEE CAEME Center is pleased to announce the availability of small grants (seed funds up to $5,000) to sponsor the development of educational software in electromagnetics with emphasis on undergraduate education. In this third round of CAEME funding, available projects that complement and enhance the utilization of CAEME software are encouraged. Areas of interest include: a) development of educational EM software packages that utilize evolving technologies such as interactive video and multi-media presentation -- some of these new developments may utilize available CAEME software; b) interactions of electromagnetic fields with materials, conduction, polarization, and magnetization; c) proposals addressing aspects of computer applications in EM laboratories; and d) innovative procedures for effective integration of available CAEME software in the undergraduate curriculum.

Proposals should consist of the following items: a description of the project including a statement of the precise objectives; explanation of procedure and schedule; a statement of how this software complements existing CAEME packages; hardware platform and software language; budget (one page).

Proposals should not exceed 10 pages, and the duration of funding may range from 6 to 12 months. A copy of the applicant's vita should also be included.

Selection criteria include: broad and significant impact of developed software on electromagnetics education; matching funds/release time commitment by principal investigator's institution; adherence to software and hardware standards set by CAEME (IBM PCs and Macintosh); commitment by PI to write a chapter in one of CAEME's books and to provide CAEME with non-exclusive license for the software.

Institutions of successful projects will be asked to sign letters of agreement which specify tasks, deliverables, and time schedules. **Deadline for submitting proposals is May 29, 1992.**

For more information, please contact Dr. Magdy F. Iskander, CAEME Director, Department of Electrical Engineering, University of Utah, Salt Lake City, Utah 84112. Telephone: 801-581-6944; Fax No.: 801-581-5281.

Are You Happy?

Are you happy with the U.S. economy? Can you look forward to a comfortable retirement, built around a secure pension, in addition to your savings and investment income? Can your engineering colleagues do the same? Chances are, you're like most engineers; you've moved around a lot in your career, or you will be moving. That's why IEEE-USA has been working for many years toward portable pensions.

We made major legislative breakthroughs in the 1970s and 1980s, and now, in the 1990s, we have used $4 ($2 per year) of your dues to create the opportunity to achieve true portability. But we cannot do it without your support and a modest additional cost to you of three first class postage stamps—87¢.

That's the cost of writing three letters—one to each of your Senators and one to your Congressman. Timing is crucial—this is an election year, and Members of Congress will not only listen, but will also respond to their constituents. So, if you're not happy, tell them about it! Ask them to co-sponsor, support and vote for H.R. 2390, the ***Pension Coverage and Portability Improvement Act of 1991***, a bill endorsed by IEEE-USA. We've worked hard to get this bill together and to get it introduced. (Not a bad return for your $4.) We need members' support to get it passed.

Handwritten letters are fine—they represent sincere concern. BUT WRITE THEM NOW! Remember, you are the IEEE-USA. Even if you have a portable pension plan, send the letters anyway, so that other engineers and other U.S. workers can be helped. A lot is at stake. With letters from our 250,000 U.S. members and their families, friends and allies, we can have a tremendous impact on Congress.

Tell your Senators and Representative that you are not being merely self-serving. Implementing H.R. 2390 will significantly enhance national savings and will help improve U.S. competitiveness in global markets. Pension funds provide much of the investment capital in this country, and industrial expansion requires capital. Passage of this legislation could be the best $4.87 investment you've ever made in your own and your nation's future.

If you need assistance in identifying your Members of Congress, consult the reference pages of your telephone book or your local public library. If you want some tips on communicating with Congress or need more information on pension issues and legislation, contact the IEEE-USA Office at 1828 L St., N.W., Washington, D.C. 20036-5104; (202) 785-0017 (office); (202) 785-0835 (fax).

Address your letters to Congress to the U.S. Senate, Washington, D.C. 20510, or to the U.S. House of Representatives, Washington, D.C. 20515.

—*Edward C. Bertnolli*, Chair
National Government Activities Committee

IEEE-USA • United States Activities • The Institute of Electrical and Electronics Engineers, Inc.

Calendar

(Continued from p. 8D)
ing, North Carolina State University, Raleigh, N.C. 27695-7911; 919-515-5704; fax, 919-515-3027.

Workshop on Combinations of Genetic Algorithms and Neural Networks (NN); June 6; Sheraton Inn Harbor, Baltimore, Md.; J. David Schaffer, Philips Laboratories, 345 Scarborough Rd., Briarcliff Manor, N.Y. 10510; 914-945-6168.

International Symposium on Electrical Insulation (DEI); June 7–10; Omni Inner Harbor Hotel, Baltimore, Md.; D. Randy James, Oak Ridge National Laboratory, Box 2008, Building 3147, MS-6070, Oak Ridge, Tenn. 37831-6070; 615-574-0266/6213.

Fifth Human Factors and Power Plants (PE); June 7–11; Marriott Hotel, Monterey, Calif.; Robert Starkey, B&W Nuclear Service, 3315 Old Forest Rd., Lynchburg, Va. 24501; 804-385-2905.

International Joint Conference on Neural Networks (NN); June 7–11; Baltimore Convention Center, Baltimore, Md.; Nomi Feldman, Meeting Management, 5665 Oberlin Dr., Suite 110, San Diego, Calif. 92121; 619-453-6222.

Sixth International Conference on Metalorganic Vapor Phase Epitaxy (LEO); June 8–12; Hyatt Cambridge, Cambridge, Mass.; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3893.

29th ACM/IEEE Design Automation Conference (C, CAS); June 8–12; Anaheim Convention Center, Anaheim, Calif.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

Conference on Precision Electromagnetic Measurements (IM); June 9–12; CNIT Paris la Défense, Paris, France; Jean Blouet, Bureau National de Métrologie, 22 Rue Monge, F-75005 Paris, France; (33+1) 46 34 4840; fax, (33+1) 46 34 4863.

Symposium on Computer-Based Medical Systems (C, EMB); June 14–17; Washington Duke Inn and Golf Club, Durham, N.C.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

International Conference on Communications—ICC/Supercomm '92 (COM, Chicago Section); June 14–18; Chicago Hilton and Towers, Chicago; P. Douglas Lattner, Ameritech Services, 2000 W. Ameritech Center Dr., Hoffmans Estate, Ill. 60196-1025; 708-248-5302; fax, 708-248-3977.

International Semiconductor Manufacturing Science Symposium (ED); June 15–17; Moscone Convention Center, San Francisco; Corinne Cargnoni, SEMI, 805 E. Middlefield Rd., Mountain View, Calif. 94043; 415-940-6950.

Fourth International Conference on Software Engineering and Knowledge Engineering (C); June 17–19; Europa Palace Hotel, Capri, Italy; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

Solid-State Sensor and Actuator Workshop (ED); June 21–25; Marriott Hilton Head Resort, Hilton Head Island, S.C.; Steve Senturia, Room 39-567; Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass. 02139; 617-253-6869; fax, 617-253-9606.

International Workshop on Hardware Fault-Tolerance in Multiprocessors (C); June 22–23; University of Massachusetts, Amherst; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013.

Graphics

Computer-generated metamorphoses evolve

Anyone who watches television regularly, or goes to the movies, has probably seen many "morphs"—Hollywood's hottest computer-generated special effect. "Morphing" describes the seamless transformation of one image into another by means of computer graphics techniques.

The effect can be startling. In Michael Jackson's "Black or White" music video, 13 faces of different races and sex appear in sequence, blending and then changing one into the other. In the movie *Terminator 2: Judgment Day,* killer robot T-1000 metamorphoses smoothly into a silver man, a silver blob, and other characters in the movie. In a television commercial for Exxon, the silver shape of a gliding car turns into the striped image of a running tiger. "The Astronomers," a six-part series produced by KCET-TV in Los Angeles, includes morphed scenes of the solar system's evolution, a journey through saturn's rings, and collisions of galaxies.

A year ago, hardly anyone had seen, let alone heard of, a morph. Now advertising agencies ask for it by name. Unlike many tools used to create an illusion, it isn't ridiculously expensive. Transformations can be done much more transparently with morphing than without, so people are shocked to see things that do not or cannot happen.

Morph effects can be obvious or subtle. A seamless transition from one image to another could be called a pure morph. "It is a cool, new effect," said Jamie Dixon, special effects director at Pacific Data Images Inc. of Los Angeles. But morphing software can also smooth over imperfections without the viewer ever noticing. It can be used to splice together different takes of a commercial or film, eliminating unusable footage and salvaging good material.

Morph segments may also be combined with real-time three-dimensional graphics. For example, to show bullet holes healing quickly in the murderous robot of *Terminator 2,* a computer graphic illustration of an expanding bullet hole was created. Next, a morphing program was used to stretch open a space on a film segment showing the actor, into which the bullet hole was placed. When the film was projected, the audience saw the 3-D computer-generated bullet hole on the actor's body shrinking until it disappeared.

The first morph sequence—in which a woman turns into a lynx—was created by Tom Brigham at the New York Institute of Technology in New York City in 1982. But the term "morphing" was coined only in 1987 by Doug Smyth, senior technical director of computer graphics at Industrial Light and Magic (ILM), part of LucasArts Co. of Los Angeles, when he improved Brigham's program. Since then, a number of other computer graphics and special effects houses have written their own morphing programs.

Morphing is short for metamorphosis, but in computer graphics the two words have different meanings. In morphing, 3-D images are stretched and deformed in the computer's 2-D domain; for example, film clips of a car engine and a bouquet of pink roses can be morphed so that the engine looks as if it is changing into roses. Metamorphosis, in contrast, refers to the 3-D transformation of one computer-rendered 3-D image into another. Thus in metamorphosis, a computer-generated image of an engine changes into a bouquet of pink roses, and then the graphic is superimposed on film.

All morphing software works along similar lines. To morph two images, the user instructs the computer—perhaps through grids of points that cover each image—to match the corresponding parts of image A and image B. For example, a point might be assigned to the nose of the cat and to the beak of the parakeet it will become. Once the computer knows the location in time and space of each point, it stretches both images toward the same intermediate shape C, somewhere between images A and B, smoothly stretching or squashing the image. Once both arrive at their respective versions of C, their intermediate images are combined. This transitional sequence is a morph.

When coupled with other digital technologies, morphing enables directors to preview special effects, add color to black-and-white movies, and correct perspective. It even lets them remove unwanted images of, say, telephone wires from Western movies, and add grain to computer graphics to match the texture of the film into which they are being inserted.

These techniques also allow directors to integrate puppets, masks, and models into movies with live actors. For the movie *Willow,* for example, scenes of puppets interacting with live actors were filmed. Later, the puppets' shapes were stretched on a computer to transform a goat into an ostrich, which in swift succession became a peacock, a turtle, a tiger, and finally a sorceress.

However, to produce a convincing morph sequence, an animator is needed. Only the creative eye can as yet determine how fast and when to move the various points on images A and B to image C, or pick the points to be matched or determine when and how fast the shapes and colors of individual regions should dissolve.

"In the future, point and pattern recognition might take place automatically, simplifying the process," said Pacific Data Images' Dixon. But the need for an animator to carry out the other creative aspects of the transformation will remain.

Morph innovators, such as Pacific Data Images and Indus—trial Light and Magic, are also developing software allowing transformations with the characteristics of a 3-D image in motion. The challenge is to morph images shot by a camera moving around an object or person. Industrial Light and Magic has already developed such a program—mksticky (for make sticky)—with which the textures of live-action footage can be mapped and "stuck" to the exterior of a 3-D model.

Although most morph software is proprietary, off-the shelf programs are becoming available. One such program, called Eddie, is available from Discrete Logic Inc. of Montreal. The software works with several animation packages. Another program, Infini-D, is available from Specular Inc. of Amherst, Mass.

© 1991 Tristar Pictures

For the movie Terminator 2, *the morphing software program Bodysock from Industrial Light and Magic was used to stretch a silver skin over a computer-generated 3-D model of an actor's body.*

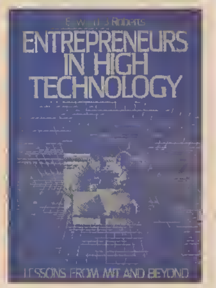
COORDINATOR: Dana Norvila
CONSULTANT: Jamie Dixon, Pacific Data Images Inc.

Books

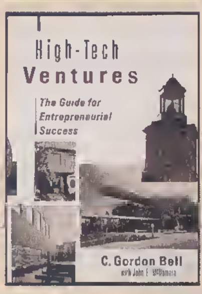
The joy of high tech entrepreneurship

Gordon Baty

Entrepreneurs in High Technology: Lessons from MIT and Beyond. Roberts, Edward B., Oxford University Press, Oxford, England, and New York City, 1991, 400 pp., $27.95.



High Tech Ventures: The Guide for Entrepreneurial Success. Bell, C. Gordon, with McNamara, John E., Addison-Wesley, Reading, Mass., 1991, 387 pp., $29.25.



Being asked to review and compare these two extraordinary books is a little like being told to review and compare the *Joy of Sex* and the *Kinsey Report*. Both deal with a topic of great and enduring interest, yet each will send the reader away with a very different set of ideas about the subject.

One tells you how to do it; the other tells you a lot about how hundreds of people have done it, what it was like, what the people were like, which practices worked, and which did not.

One academic wag once separated all writing on entrepreneurship into two piles: "knowledge" (based on research, data, and statistical inference); and "normative folk wisdom" (based on having "been there, done that," and wishing to help others succeed). Professor Roberts and Mr. Bell are each admirably qualified to do what they have done: write the quintessential examples of "knowledge" and "normative folk wisdom" on technology entrepreneurship. Both are highly recommended for the engineer-entrepreneur (and would-be engineer-entrepreneur).

At the outset, I should make it clear that I am a product of the same Route 128–Massachusetts Institute of Technology (MIT) culture that produced both authors, and my career as a technical entrepreneur, venture capitalist, and sometime-teacher of entrepreneurship owes a substantial debt to both men. Roberts, first through his research and teaching, and later through his involvement in my venture capital firm, has offered information, ideas, and encouragement for many years. Bell, on the other hand, through his instrumental role in the success of Digital Equipment Corp., Maynard, Mass., has made a huge contribution to the self-sustaining Route 128 phenomenon.

Roberts's book will stand out as an enduring contribution to a rapidly growing body of academic writing on entrepreneurs, entrepreneurship, and venture capital. It will do so not only because it is based on more information and data than anyone else's (over 40 research studies on about 400 MIT spinoffs, conducted over 25 years) but also

(Continued on p. 16)

Your favorite technical handbooks are now available in soft editions.

A new approach to math.

Introducing the Mathcad 3.1 Software System for Microsoft Windows or UNIX. It revolutionizes math by letting you zip through problems naturally and logically—because it works the way you think. And now it's even more powerful, thanks to new Electronic Handbooks.™

PC MAGAZINE EDITOR'S CHOICE
Mathcad 2.5
3-14-89 issue.
Best of '88
Best of '87

More than a number-cruncher.

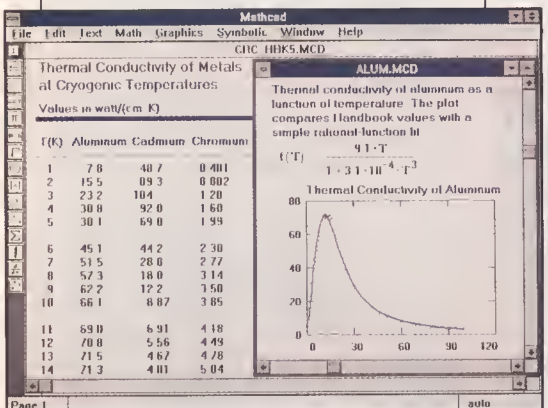
With Mathcad 3.1, you type your work anywhere into the live screen—just like you'd write on a scratchpad—and Mathcad does the calculating. Updates answers when a variable changes. Even graphs in 2-D or 3-D.

Symbolic calculation capabilities let you do integrals, Taylor series, or infinite sum calculations with click-n-drag simplicity.

And when you're done, Mathcad prints out presentation-quality documents complete with equations in real math notation.

Fast electronic access to commonly used methods, formulas and diagrams.

Mathcad's new Electronic Handbooks give you instant access to the formulas, methods, diagrams and tables you rely on every day. Just open an Electronic Handbook and select your topic. They're interactive, so you can modify formulas for specific calculations. Change parameters, plots and variables, and let Mathcad automatically calculate your answers within the Handbook. Or double-click on a Handbook entry and paste it into your Mathcad document—with the correct units!



Three new optional Mathcad Electronic Handbooks* are now available, each created in conjunction with a leading publisher of technical reference handbooks:

- **Mathcad Treasury of Methods and Formulas** offers you a host of the methods, formulas and diagrams you use every day, along with interactive explanations of every feature and algorithm of Mathcad.
- **Machine Design and Analysis** from Hicks' *Standard Handbook of Engineering Calculations* from McGraw-Hill, contains more than 125 practical calculation procedures including shaft and gear mechanics, time and power to cut, drill, bore, countersink, and a lot more.

PC MAGAZINE — THE BEST OF 1991 — COVER STORY

- The **CRC Materials Science and Engineering Handbook** contains more than 140 tables of data, bit-mapped illustrations, and Mathcad plots. Includes densities, melting points and crystal structures of elements, properties of ceramics and superconducting materials, and much more.

Also Available:

- **Optional Applications Packs**—adaptable Mathcad templates for Electrical, Mechanical, Civil and Chemical Engineering, Statistics, Advanced Math, and Numerical Methods.
- PC DOS and Macintosh® versions also available.

Free demo disk.

For a FREE Mathcad demo disk, or upgrade information, call 1-800-MATHCAD (or 617-577-1017, Fax 617-577-8829). Or see your software dealer.

UNIX Version now available

*Electronic Handbooks require Mathcad 3.1 and Microsoft Windows 3.0 (or higher) or UNIX.

1-800-MATHCAD

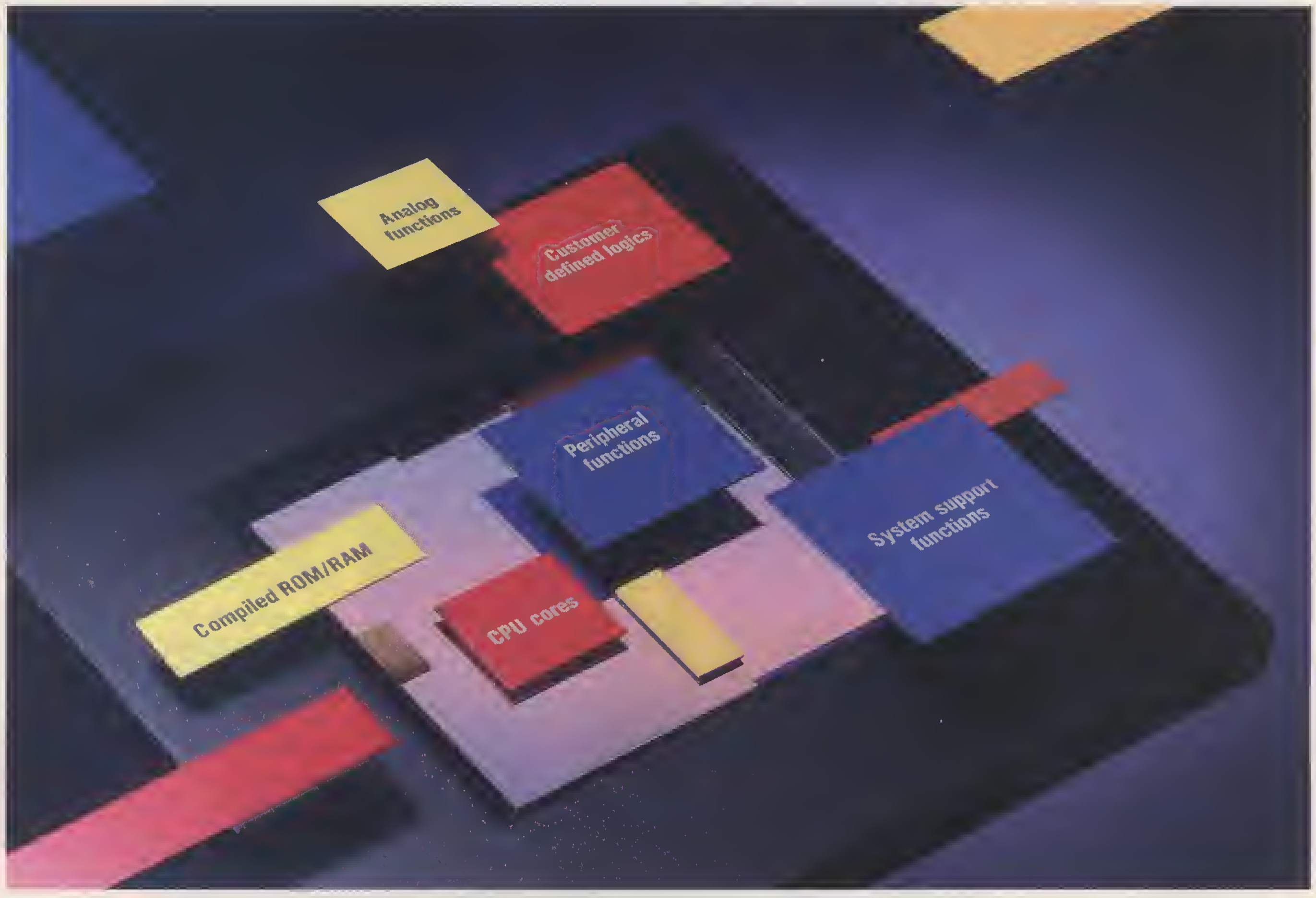
The answer is Mathcad®

MathSoft, Inc. 201 Broadway, Cambridge, MA 02139 USA • Phone: 1-800-628-4223 • 617-577-1017 • Fax: 617-577-8829

Australia: Hearne (03) 866 1766; Belgium: SCIA 013/55 17 75; Denmark: Engberg 42 25 17 77; Finland: Zenex 90-692-7677; France: ISE (1) 46 09 24 00; Germany: Softline (0 78 02) 4036; Italy: Channel 02-90091773; Japan: CRC 03-3665-9741; Netherlands: Klaasing 01620-81600; Sweden: AkademiData (018) 24 00 35; Switzerland: Redacom 032 41 01 11; U.K.: Adept Scientific (0462) 480055. In other locations, contact MathSoft, USA.

Circle No. 11

NEC NEWSCOPE



CELL-BASED ICs ARE BUILDING BLOCKS FOR "SYSTEM ON SILICON".

The industry's first sub-micron, cell-based ASICs are generating keen interest. Designers worldwide see them as an efficient approach to the long-awaited "system on silicon."

NEC's CB-C7 cell-based ICs have won more than 30 design-ins since their introduction in April, 1991. Applications range from PCs, disk drives, printers, copy machines and facsimiles to cellular phones, VCRs and games.

The CB-C7 achieves high speed and high density through a 0.8μ CMOS process. It offers 0.33ns power gate delays* and densities of up to 180,000 gates. *$F/O = 2$, $l = 2mm$

The macro cell library is exceptionally large. It includes industry-standard V20H/30H 16-bit CPU cores, DMA controller, floppy disk controller, graphic display controller, and AD/DA converters. RAM and ROM can be compiled to precisely match system requirements.

For fast turnaround, customer-defined logic can be implemented in a sea-of-gates structure on the base array. To minimize chip size and cost, the entire ASIC is fabricated with standard cell technology.

NEC provides a complete front-to-back-end unified design environment. With our OpenCAD Design System™, designers can use industry-standard CAD tools on popular workstations to design CB-C7 ICs.

NUMBER 147

WORLD'S FIRST OPEN-NETWORK DCME SYSTEM.

Digital Circuit Multiplication Equipment (DCME) is a key system for international communications via satellite and submarine cable. NEC's NCM-501 DCME system is the first to offer open-network freedom in this environment.

Using DSI* and VBR-ADPCM** techniques, the NCM-501 system multiplies circuit capacity by an average of five times. It meets all relevant INTELSAT, EUTELSAT, and CCITT standards.

The NCM-501 is easily configured for an Intermediate Data Rate or a TDMA/DSI satellite system. It is also equipped for ISDN services.

NEC's DCME system provides four operating modes: Multi-destination mode for up to four parties sharing a common interpolation pool; multi-clique mode for two destinations using separate pools; single destination mode; and mixed multi/single destination mode.

NEC's open-network DCME systems have already been delivered to more than ten countries.

**Digital Speech Interpolation. **Variable Bit-Rate Adaptive Differential Pulse Code Modulation.*

DCME system configured for 7: 1 protection.

ENHANCED MULTISYNC COLOR MONITORS.

MultiSync® displays were originated by NEC and have become the industry's most popular multiple frequency monitors.

Now NEC has developed an enhanced MultiSync monitor, ideal for graphics-intensive windowing environments.

The enhanced version features a flat, square screen and digital color controls. The high-resolution screen provides sharper images from edge to edge and top to bottom. It's 20% brighter and virtually flicker-free. New MultiSync monitors also feature NEC's exclusive AccuColor™ control system. AccuColor allows users to adjust on-screen colors to suit individual needs or tastes. It controls the red, green and blue guns separately in precise digital steps.

Advanced digital controls also automatically size and center screen images for preset and custom graphics modes. Ergonomic features range from the cabinet design to the antistatic, low-reflection screen. The Reduced Magnetic Field™ technology employed in the new monitors meets strict Swedish MPRII guidelines.

NEC's new MultiSync monitors are available in 15, 17, and 21-inch models.

622.08Mbps SONET/SDH DATA LINK.

NEC has developed a super-fast optical data link called NEOLINK-6211. The device is intended for processor links in switching systems, LANs and backbone loops in the emerging SONET/SDH era.

NEOLINK-6211 is the industry's most compact 622.08Mbps data link featuring 3R functions — reshaping, regenerating and retiming. The transmitter measures 39 x 58 x 8.9mm; the receiver 39 x 76 x 8.9mm.

The link spans about 10km with transmitter output power of −13dBm and receiver input power between −26dBm and −10dBm (BER: 10^{-10}).

NEOLINK-6211 transmits through 10/125μm single-mode fiber via a 1.3μm laser diode/PIN photo diode pair. The interface is differential ECL. Power supply requirement is a single −5.2V DC.

NEC offers an evaluation board to speed up your design process.

NEC

Books

(Continued from p. 12)
because Roberts is a skillful writer, reducing his findings to useful generalizations for the scholar and entrepreneur alike.

In chronicling the earliest spinoffs from the labs and academic departments of MIT, Roberts captures a fair bit of the "look and feel" of those days, on top of the factual documentation that scholarship demands. Generations of Sloan business school graduates have participated in these studies, many of whom went on to form their own companies (and generate more studies).

The research has followed five tracks: spinoffs from MIT; spinoffs from MIT-affiliated organizations (such as the Mitre Corp. and the Air Force's Cambridge Research Laboratory); samples of ventures from specific high-tech industries; studies of the psychology of founders; and studies of various aspects of the financing of ventures. Taken together, this broad focus, huge database, and long timeframe result in an unparalleled study of a phenomenon that has changed the world.

Entrepreneurs and would-be entrepreneurs will find food for thought about, if not direct answers to, some of their most profound questions. Just how important to success is technology transfer? What are the characteristics of the most—and least—successful entrepreneurs? How do venture capitalists really evaluate business plans? What sources of capital, besides venture capital, should a start-up seek?

Bell, perhaps best known for leading the development of the pioneering PDP-8 minicomputer at DEC, has written quite another sort of book. Based on his many years of directing large technology projects, as well as participating in high-profile start-ups, such as that of the now-defunct Stardent Computer, he has created a "diagnostic," a kind of very comprehensive checklist, for evaluating a young or proposed company's chances of success. This checklist and the procedures he proposes for its application could be quite valuable to the engineer-entrepreneur contemplating launching a start-up, but could also be quite useful to the investor.

My own venture capital firm employs a much more modest version of Bell's diagnostic, not only to evaluate individual projects, but to establish a standard format for due-diligence investigations, so that we may compare different deals. If we could implement Bell's more comprehensive checklist, it would doubtlessly improve both the effectiveness and quality of our investigations.

Academics will certainly say that Bell adds nothing new to our knowledge about entrepreneurship or about the study of ventures, but such thinking misses the point. In distilling his decades of shirt-sleeve practitioner's knowledge, ideas, and intuition into a diagnostic checklist, Bell is giving other practitioners a powerful, condensed lesson in what is most likely to work in the real world.

In the end, though, the user is still left with all the subjectivity and guesswork (Is this really a good team? Will the market for this product really be US $1 billion by 1997?). Nobody knows the answers to questions like these, but at least Bell's diagnostic provides a framework within which to make the guesses, to document that they were made, and to approach a logical conclusion. These are all essential chores.

My only quibble is with the title of the book, which might lead some readers to believe the book is more general than it really is. A more accurate title might have been: *The Guide to Entrepreneurial Success in High-Profile Computer Hardware Ventures*. My definition of high-tech includes biotechnology, telecommunications, materials science, automation and instrumentation, and a lot of other high-growth industries and endeavors. Virtually all Bell's examples, illustrations, and "war stories" are drawn

(Continued on p. 76)

Legal aspects

Speaking with the enemy

Joel Miller

You've just received a call from a lawyer representing Mr. Jones, a former employee of ABC Corp. who was seriously burned last year in ABC's high-voltage laboratory when a circuit breaker failed to trip. His attorney wants to ask you some questions about the matter since you were in the lab at the time of the incident. Indeed, you can still remember hearing his anguished cry for help.

But, having left ABC yourself two months ago, you're uneasy about the request for information. Should you answer the lawyer's questions? For that matter, should the lawyer be asking you questions in the first place?

THE QUEST FOR INFORMATION. Lawyers make such telephone calls frequently, particularly in major lawsuits, because informal interviews are a quick and inexpensive way of obtaining leads and evidence. Corporations, however, oppose informal interviews, arguing that any employee—current or former—has certain obligations to the corporation, and that unrestricted access to them could be detrimental to the corporate interests. Instead, most companies insist that employees be asked questions only in the presence of their attorneys or in a formal deposition, that is, where the proceedings are recorded by a court reporter and attended by all parties in the lawsuit.

Unfortunately for the inquiring attorney, this may not yield the hoped-for information as the presence of the corporation's lawyer will likely inhibit an otherwise impartial employee from speaking freely. Also, if the lawyer has to take formal depositions of every potential witness, the sheer cost (of his own time in preparing the questions and taking the deposition, plus that of the transcript) will be astronomical compared to that of a half-hour telephone call or a brief meeting.

Consequently, many litigants would prefer to interview employees without the presence of the corporation's lawyer—a communication referred to as *ex parte* in legal shorthand. Are *ex parte* interviews of employees, current or former, allowed under the law? If so, just how far can an opposing lawyer go in picking an employee's brain?

The answer to the first question is, yes, informal interviews are permissible, under certain circumstances. The answer to the second is trickier. Several courts have ruled on these questions, but neither the ultimate decisions nor the underlying reasons have been uniform. The lack of agreement has spurred a continuing debate within the legal community as to what is permissible. Nevertheless, there are established principles that can help determine who can be contacted informally and the kinds of information that can be sought, the most pertinent being the Model Rules of Professional Conduct.

ETHICAL RESTRICTIONS. The Model Rules are ethical guidelines formulated by the American Bar Association and adopted by the various states. They prescribe in part how attorneys should conduct themselves in their dealings with opposing parties, witnesses, and the public. Of interest here is Rule 4.2, which states that a lawyer cannot communicate directly with a person represented by counsel. Instead, the person's attorney must be contacted first.

While it is obvious that the corporation itself is represented by its attorney, what about its employees? Is every employee from the president down to the janitor on the night shift represented by the corporation's attorney and thus unapproachable?

Probably not. As applied to a corporation, a "person represented by counsel" has been interpreted to mean a person having managerial responsibility, or a person whose act—or failure to act—in connection with the underlying matter may be imputed to the corporation for liability purposes, or anyone whose statement would be binding upon the corporation by virtue of that person's role in the matter.

One of the leading cases on this issue is *Nieseg v. Team I*, decided by the New York Court of Appeals in 1990. While working at a building construction site owned by Team I, Thomas Nieseg fell from scaffolding and was injured. Since his co-workers had witnessed the accident, Nieseg's attorney sought to interview them privately.

Construing the predecessor to Rule 4.2, the court allowed the interviews. Essentially bystanders, they were not in a position to legally bind their employer, they had no involvement with their employer's attorney, and their own interests were not at stake.

NO TROJAN HORSES. Under the Model Rules, an attorney must observe certain formalities in approaching an individual believed to be unrepresented. Model Rule 4.3 requires the lawyer to clearly indicate his or her role in the matter and to be certain that the interviewee understands this.

Often, an attorney will employ a non-lawyer to conduct an *ex parte* interview. This does not, however, circumvent the ethical rules as that person is the agent of the attorney, who is responsible for the non-lawyer's conduct.

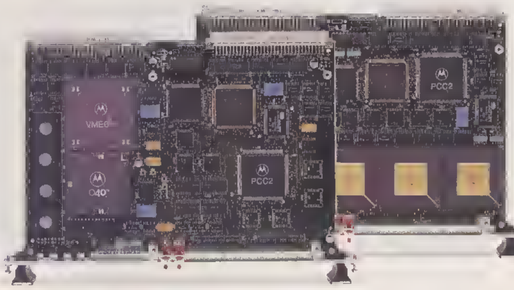
In a suit brought by Monsanto Co. in Delaware, defense counsel hired investigators to conduct *ex parte* interviews of Monsanto's former employees. On several occasions, the investigators acted improperly: by neg-

(Continued on p. 81)

BUSCON '91 East Product of the Year.

Some people think we're power crazy, obsessed with quality and downright cheap.

And it's all true.



Okay, we admit it. We're hopeless perfectionists. Driven to produce the best boards at the best price.

Take our new MVME187 and MVME167 single board computers, for instance. Best in performance at 38 MIPS* (RISC) and 26 MIPS* (CISC), respectively. Best in value at $105 (RISC) and $154 (CISC) per MIPS.

Which comes out to just $3,995 per board. And which compares rather nicely with the $8,000 to $12,000 you could pay for the competition's boards. Based on the 88100 and 68040, Motorola's highest performance 32-bit microprocessors, the MVME187 and MVME167 employ VME D64 architecture. Boosting the VMEbus bandwidth to a full 40MB/s. And both boards come with four 32-bit timers, as well as SCSI and Ethernet connections.

Naturally, since they're made by Motorola, you can expect the best in quality. The Malcolm Baldrige Award is a powerful testament to that fact.

Malcolm Baldrige National Quality Award

So call 1-800-234-4VME for a free color brochure. And see why so many people are obsessed with Motorola products.

MOTOROLA
Computer Group

For a free color brochure, call 1-800-234-4VME.

Circle No. 21

Spectral lines

APRIL 1992 Volume 29 Number 4

The ethics of argument

Do engineers resolve conflicts in a more civilized manner than others (normal people)? Folklore has it that we do—or should, at least. In the early years of the century, when the profession was just beginning to define itself, engineers were anointing themselves as dispassionate, logical decision-makers in all kinds of matters. They believed, and often wrote, that the logic and impartiality of science applied also to engineering, and hence to its practitioners.

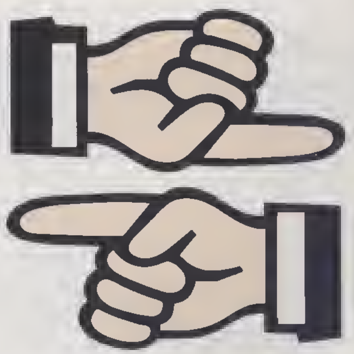
The implication seemed clear. While lawyers, the clergy, and a technically illiterate general public might resort to emotion and rhetoric to win points or reach decisions in complex situations, the clear-thinking engineer (or scientist) would apply his superior skills to reaching better solutions—and without the discomfort associated with ill-conceived argument. The latter encouraged bombast and speciousness, and ultimately shifted the argument from the issue at hand to personal attacks by the debater(s). Engineers protested, and still do, that such mud-slinging is to be expected from politicians who are handicapped by an inferior understanding of the issues, but not from engineers, whose superior knowledge means that they need not stoop to *ad hominem* attacks.

Edwin Layton, a professor of mechanical engineering and historian of technology, recalls the origins of the engineers' self-proclaimed superiority in logic in his classic *The Revolt of the Engineers*.* He wrote:

> . . .engineers concluded that they, as individuals, were peculiarly liberated by their profession from the usual human limitations, and therefore superior to other groups. One prominent electrical engineer [who was president of the American Institute of Electrical Engineers (AIEE) in 1919] maintained that "the vast majority" [of the populace] accepted "superficial, partial, and biased statements," concerning socio-economic questions, but that engineers, because they must live by "immutable laws" and must verify facts, think straight. Another engineer [in 1908] spoke of the "position in society which belongs to us by right of education, achievement, and highly developed powers of logical deduction."

In contrast to these early preachings about engineering superiority and coolness under fire, we have stories of clashes between electrical eminences like Sir William Henry Preece and Oliver Heaviside, and David Sarnoff and Edwin H. Armstrong.

Preece and Heaviside cut one another up in print as well as from the podium. With obvious reference to his strong disagreement with Heaviside, Sir William in his inaugural address as president of the Institute of Electrical Engineers (IEE) remarked that the "advance of our knowledge in this branch of electrical engineering has been very much retarded by the phantasies of visionary mathematicians [read Heaviside] who monopolize the columns of our technical literature and fill the mind of our student with false conclusions." Heaviside, for his part, published his share of sharp attacks on his nemesis' prowess as an engineering theorist.



In all fairness, while their disagreements were real, both exhibited a certain wit and flair in their arguments. Perhaps, being British, they took a cue from the House of Commons, whose boisterous arguments are replete with acerbic insults, catcalls, and inharmonious jeering.

In the case of Sarnoff and Armstrong, on the other hand, the arguments were equally real but, particularly for Sarnoff, business-based. While Armstrong—directly and emotionally involved—sought recognition and recompense for his inventions from his erstwhile friend, Sarnoff stood above the fray, sending his lawyers into the battle.

The tactics in the bitter contest were not always fair, nor the issues always honestly and openly defined. Ultimately, Armstrong, more concerned about his reputation and recognition, became the big loser.

Other disagreements relating to credit and patent ownership over the years proved that engineers can be just as human as normal folk when it comes to emotional and illogical reactions. We can present superficial arguments and partial truths in defense of a position as easily as the lawyer or layperson can.

As a general rule, combatants in any field tend to adjust their combative methods to the situation, or to the "game" at hand. For example, an engineer invited to comment orally, before an audience, on a paper presented by a colleague, may offer several compliments before suggesting areas for further research, and—only then—perhaps noting some facts that may be in dispute. In a written review of the same manuscript, however, the engineer might be more direct, writing "Absurd!" and "Hogwash!" in the manuscript's margin. (The reviewer's position lends him a certain protection that encourages more blatant, if less helpful, commentary.)

It is useful in conflict resolution if both parties are playing the same game, and playing it according to the same rules. Thus it may have been that the Sarnoff-Armstrong disagreement was doomed from the outset, since Armstrong saw the issue as fairness to his reputation, while Sarnoff may have viewed the whole affair as one of dollars and cents, with "all's fair in business" as his guiding credo.

In this column, we have begged the question of whether engineers do, more than they once did, conduct their arguments, technical or otherwise, in a more civil manner than others. It is hard to tell. Perhaps the general permissiveness of society has eroded the civility and fairness once attributed to the profession by its practitioners.

Perhaps engineering and engineers have become assimilated into the general populace insofar as distinctiveness in debating methods goes. Perhaps we have no Marquis of Queensberry rules that could be supported by, as our forebears hinted, our purported superiority in logic and intelligence.

Perhaps we never did.

Donald Christiansen

**The Revolt of the Engineers: Social Responsibility and the American Engineering Profession*, Edwin T. Layton Jr., Johns Hopkins University Press, Baltimore, Md., and London, 1971 (reprinted 1986).

In this two-part report, IEEE Spectrum *describes the Iraqi nuclear program and considers the future of nuclear safeguards in the wake of the Cold War*

Part 1: How Iraq reverse-engineered the bomb

Two weeks into the war in the Persian Gulf, a U.S. pilot was heading north after bombing primary targets near Baghdad. A quick check of his instruments and his list of secondary targets convinced him he had the time, fuel, and munitions left for a run at Al Tarmiya, an industrial site, before flying back to base in Saudi Arabia.

U.S. intelligence had identified a plant at Tarmiya as a military nuclear facility, but knew little else about it. Analysts believed that Iraq was struggling to build a plant there for uranium enrichment, based on the centrifuge technique, a standard method of enriching uranium to weapons-grade. But Tarmiya's low priority as a target reflected the intelligence community's belief—very much mistaken—that Tarmiya was not one of Iraq's most important nuclear sites.

Taking aim at one of the large halls, the pilot rolled in and dispatched two Hellfire missiles, which inflicted light damage.

Within a day or so, however, routine aerial reconnaissance revealed hundreds of Iraqis at the site, "busy as hell, tearing out large pieces of equipment" to conceal and protect it, according to a source familiar with the episode. Unwittingly, the coalition had just struck one of the most critical components of a sprawling nuclear program whose size, scope, and achievements far exceeded the most alarmist estimates of the time. David A. Kay, a former inspector with the International Atomic Energy Agency (IAEA) in Vienna and now secretary general of the Uranium Institute in London, believes that Tarmiya would have been Iraq's first industrial-scale site capable of producing weapons-grade uranium. And though the allies did not know that until much later, the frantic activity after the bombing told them all they needed to know for the time being. Within days, B-52 bombers were sent back to "plaster" the site thoroughly, according to *IEEE Spectrum*'s source.

Glenn Zorpette Senior Associate Editor

How could Western intelligence have been so blind to the purpose and scope of such a key site? As with many other questions about the forging of the Iraqi war machine, the answer lies partly in the Iraqis' skill in deception and partly in the largely coincidental eight-year war with Iran in the 1980s.

Had it succeeded, Iraq's attempt to produce a nuclear weapon might one day have yielded a stunning case study of concurrent engineering. As it turned out, the Iraquis pursued many phases of development in parallel, and closed off options only when they presented truly insurmountable obstacles. This held true both for their production of weapons-grade material and for their construction of a deliverable weapon. The crash program also employed elements of reverse engineering, exploiting projects and developments that had been abandoned by earlier experimenters in the United States and elsewhere. And it drew heavily on materials, hardware, and information acquired from outside the country, in some cases illegally or unethically.

> Iraq spent billions of dollars and employed at least 12 000 people in its pursuit of an atomic bomb

INTELLIGENCE LAPSE. The uranium enrichment technique being pursued at Tarmiya was, astonishingly enough, electromagnetic isotope separation. Nowhere else had this extremely inefficient method been used for an atomic weapon apart from the Manhattan Project in the United States during World War II. As the process uses vast amounts of electricity, the Iraqis constructed a power plant with an output in excess of 100 MW, and devoted it to the Tarmiya facility. But in case the dedicated use of so much electricity should seem suspicious, the power plant was located 15 km from Tarmiya, and connected to the facility by underground cables.

Tarmiya itself was surrounded by only a light fence, giving U.S. intelligence analysts the impression that whatever was going on inside could not matter much. What the analysts overlooked, according to *Spectrum*'s source, was that the entire area around Tarmiya was a military exclusion zone, so a more impenetrable fence was not needed. Moreover, the United States may not have scrutinized Tarmiya intensively from above during the Iran-Iraq war, when most reconnaissance assets were focused on border areas between the two countries, according to intelligence sources.

Overall, Tarmiya is typical of how Iraq combined not just deception and strict secrecy, but also hard work and research, exploitation of the open literature on nuclear science, illegal acquisitions, and the expenditure of huge sums of money to put together an immense program for nuclear-weapons development. In fact, its exact dimensions and scope are still not fully known, and may never be, according to Kay and others who have investigated it. The best current estimates are that the country spent the equivalent of billions of dollars—perhaps even US $10 billion—over a decade and employed at least 12 000 people in its pursuit of an atomic bomb.

The bad news is that at the time it invaded Kuwait, Iraq was probably only 12–18 months away from a crude but useable nuclear device, according to Kay. Other esti-

0018-9235/92/$3.00©1992 IEEE

When enlarged, this photo (above) was the "smoking gun" that proved that Iraq was attempting to hide parts of its uranium-enrichment program from international inspectors, who were fired on as the photo was taken. The photo shows an Iraqi tank-transporter truck carrying a calutron part out of the back gate of a military site at Fallujah. The part—a vacuum chamber housing a calutron's ion source and collectors—was later found buried at a site west of Baghdad (top). Many other calutron parts were found at sites in the desert west and north of Baghdad.

mates, corroborated by documents in the IAEA's posession, put the figure in the range of 25–40 months, according to Maurizio Zifferero, head of the IAEA "action team" set up to investigate and dismantle the Iraqi nuclear program. (Contrary to previous reports in the popular press, Iraq did not have dozens of kilograms of hidden bomb-grade uranium, one or two working weapons and the ability to produce 20–40 more, or an ongoing project to build a thermonuclear weapon, according to the IAEA.)

The "good" news, nonproliferation experts hasten to add, is that the country was in many ways unique: it had plenty of capital from its oil sales, a relatively impressive technical infrastructure, many highly competent engineers and scientists, and a dictatorial regime that could easily conceal huge expenditures on a single military objective.

OUTSIDE HELP. The Iraqi nuclear program started in the 1960s, with the purchase of a 2-MW Soviet light-water research reactor. But, ironically, the effort to build a bomb can be said to have begun in earnest in 1981, the year Israeli pilots bombed and demolished Tammuz I, a French research reactor with a rating of about 50 MW.

"When the Israelis destroyed Tammuz, the Iraqis met and decided to change their

IRAQ'S NUCLEAR PROGRAM, FROM MINING TO TESTING

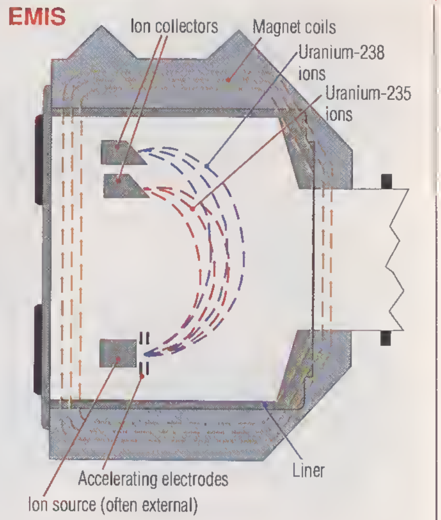
Acquisition of uranium ore

During the 1980s, Iraq purchased at least 450 metric tons of yellowcake, a uranium oxide refined from ore, from Brazil, Portugal, and Niger. Iraq also mined uranium ore at Akashat and produced some 164 metric tons of yellowcake domestically.

Production of highly fissile nuclear materials for weapons

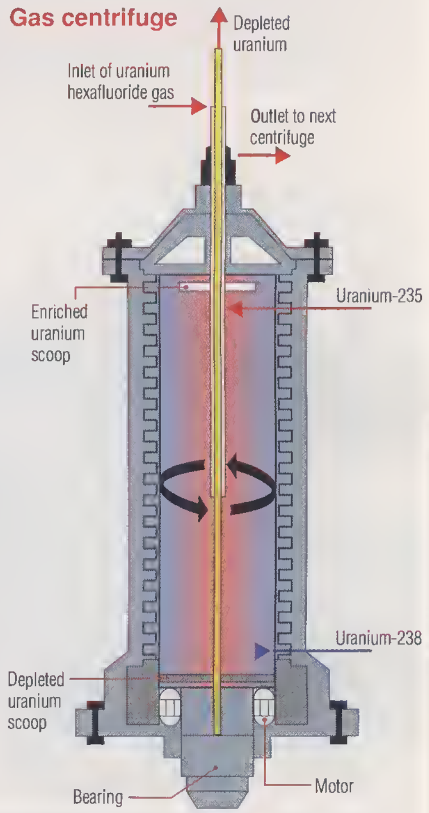
Iraq investigated every method ever devised for enriching uranium to weapons-grade, but concentrated especially on two: electromagnetic isotope separation (EMIS), and gas centrifuge.

With **EMIS**, a stream of uranium ions is deflected by electromagnets in a device called a calutron. The heavier U-238 ions are deflected less than the U-235 ions, and this slight difference is exploited to accumulate the highly fissile U-235.



In a **gas centrifuge**, uranium hexafluoride is spun in cylinders with diameters of about 75–400 mm. Centrifugal forces push the heavier U-238 to the cylinder wall, while the U-235 tends to collect closer to the center of the cylinder. For the process to be industrially effective, many centrifuges must be linked in a cascade. Experts disagree on whether Iraq had such a cascade at the start of the war in the Persian Gulf.

There are also indications that Iraq was attempting to produce plutonium—the fissile material used in most modern bombs. To produce plutonium, uranium is irradiated in a reactor and the plutonium is separated out of the resulting material. In addition to producing a small (militarily insignificant) amount of uranium in this way in a Soviet reactor, some experts now believe that Iraq had an as-yet undiscovered reactor for this purpose.



policy,'' Zifferero explained. The decision was to ''enshroud in secrecy all activities having to do with their nuclear capabilities, and to duplicate all [key] installations in case any part was discovered and destroyed again by Israel,'' Zifferero told *Spectrum* in late January during an interview at IAEA headquarters in Vienna.

Thus at the time of the invasion of Kuwait, construction was well under way on a duplicate of the Tarmiya installation, at Ash Sharqat, 300 km northwest of Baghdad. Like the Tarmiya facility, Ash Sharqat was fed by underground cables from a sizeable remote power source. During the Gulf War, coalition intelligence had pattern-matched the layouts of Ash Sharqat and Tarmiya, on the basis of aerial reconnaissance, and Ash Sharqat was also bombed, according to an official with access to intelligence documents.

But so far, Kay noted with concern, Tarmiya and Ash Sharqat are the only twin facilities discovered by investigators. He said he confronted his Iraqi contacts, demanding to ''see the duplicates of your other facilities''—but to no avail. ''You could have just cut the consternation with a knife,'' he said. ''And [the Iraqis] haven't come up with any other duplications yet.''

The French sold Tammuz 1 (also known as Osirak) and Tammuz 2, a 0.5-MW reactor used for studies of the larger reactor, to Iraq in the mid-1970s. Both used uranium fuel enriched to 93 percent U-235, which is bomb-grade material. This material was subject to regular IAEA safeguards as a condition of the French sale, however, so Iraq could not have used it to produce a bomb without openly flouting IAEA regulations. Furthermore, some of the French fuel was lightly irradiated (used) in Tammuz 2, slightly reducing its utility for weapons-making.

Nonetheless, Iraq managed to separate a few grams of weapon-type plutonium from additional, indigenously produced fuel rods irradiated in the Soviet reactor, according to the IAEA. A few grams is not nearly enough to make a bomb—about 8 kg are needed—but its creation was one of many flagrant violations of the Nonproliferation Treaty (NPT) that Iraq had signed in 1969.

The Iraqis were studying plutonium for at least two reasons, according to Kay. He said they were interested in plutonium production, noting that most atomic bomb designs are based on plutonium, or on mixtures of plutonium and highly enriched uranium. It ''shows that they did not leave a single route unexplored,'' he said.

In mid-February, news accounts suggested that Iraq had an as-yet undiscovered underground nuclear reactor capable of producing enough plutonium for several bombs a year. Prompted by intelligence information from France and other countries, inspectors from the IAEA and the United Nations searched several sites, including one 120 km north of Baghdad, but to no avail. Nonetheless, many analysts remain convinced the reactor exists.

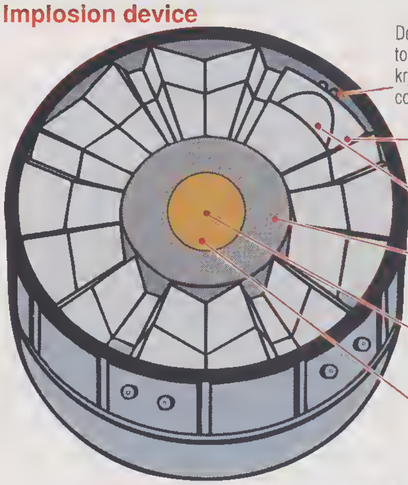
''All of the facts support the existence of a plutonium reactor,'' Kay said. The Iraqis had vast amounts of uranium ore, and the ability to fabricate it into fuel rods, both of which are difficult to explain without the existence of such a reactor (the French and Soviet reactors were for the most part fueled by separate fuel assemblies).

Apparently, the Iraqis were also investigating the use of a plutonium isotope, Pu-238, as an initiator—the bomb component that supplies neutrons to begin an atomic explosion. Iraq was having trouble producing the polonium isotope normally used for this purpose, Kay said.

Design and construction of nuclear weapons (weaponization)

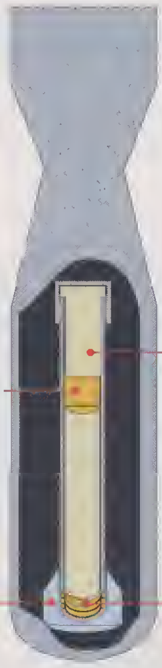
There are two main atomic bomb designs: implosion weapons and gun devices. For a given amount of nuclear material, implosion weapons produce much higher explosive yields, but are much harder to design and build.

Implosion device



In an **implosion device**, conventional explosives set up a collapsing spherical shockwave, which compresses the highly fissile core. At just the right instant, neutrons are released, triggering the nuclear chain reactions and producing an atomic blast. Iraq had made significant progress toward developing an implosion device, but had not been able to build one before war broke out in the Gulf.

Gun device



In a **gun device**, two samples of highly fissile material are slammed together in a tube with tremendous force. Although no evidence has been found yet to indicate that they had done so, Iraqi engineers and scientists "knew everything necessary to make a gun-assembly device," according to a top expert on the Iraqi nuclear program.

Illustration sources: Richard Rhodes, *The Making of the Atomic Bomb* (Simon & Schuster, New York, 1988); *The Bulletin of the Atomic Scientists* (Washington, D.C., March 1991); *The Financial Times* (London, Jan. 15, 1992).

Weapons testing

Although investigators have not found a site in Iraq where a full nuclear weapon test could be carried out, ample evidence has been found that smaller-scale tests on weapon parts were carried out. For example, assemblies of conventional explosives, plus so-called "lenses," were tested at a site not far from Al Atheer. Some evidence has also been found that the Iraqis had carried out at least preliminary tests in the use of conventional explosions to compress depleted (unenriched) uranium, to study the symmetry and simultaneity of shock waves.

On the other hand, obtaining uranium, from which plutonium is derived, was not a problem for Iraq.

NO STONE UNTURNED. During the 1980s, the country legally purchased some 440 metric tons of yellowcake, a uranium oxide concentrate obtained from ore, from Portugal and Niger. But 27 tons of uranium dioxide were bought from Brazil and the transaction was not reported to the IAEA, in violation of Iraq's NPT obligations. In addition, Iraq had secretly produced some 164 tons of yellowcake domestically, at Al Qaim, from a phosphate mine at Akashat. The uranium-processing equipment at Al Qaim was reportedly built by a Swiss firm, Alesa Alusuisse Engineering AG. An Alesa spokeswoman, however, denied that her company had had any direct dealings with Iraq.

Although not the most common weapons material, highly enriched uranium can of course also yield atomic bombs and here, as in most aspects of the Iraqi nuclear program, the overriding characteristic of the effort was its all-inclusiveness. At one time or another during the 1980s, Iraqi engineers and scientists were either actively developing or studying the available scientific literature on every method ever used to enrich uranium to weapons grade.

According to investigators, Iraq supplemented its own attempts to develop enrichment equipment with extensive clandestine efforts to illicitly acquire other equipment, information, and materials. Much of this came from European and U.S. companies, and at least a few rogue nuclear experts. Sometimes the purchases were made through intermediary organizations. To further confuse any would-be inquisitors, the Iraqis named their clandestine nuclear program Petrochemical Project #3 (PC-3).

Although the Iraqis considered every means of enrichment, they quickly discarded gaseous diffusion and laser separation, because these techniques required technologies and resources beyond their means. (In fact, laser separation is still experimental, but considered a promising technology in the United States and Europe.) That left three techniques: electromagnetic isotope separation (EMIS), which was to have first gone to industrial scale at Tarmiya; gas centrifuge; and chemical separation.

'CREATIVE AND LEGAL.' Ultimately, work on chemical separation in Iraq took a back seat to the other two techniques, but the country's pursuit of the technology is illustrative of its methods. France and Japan developed different chemical enrichment technologies in the late 1970s. The Japanese process depended on expensive, esoteric resins whose purchase would be hard to disguise, so the Iraqis chose the French process. In the early 1980s, they entered into negotiations with the French to buy the process, which was called Chemex and based on liquid-liquid solvent extraction.

The Iraqi version has the negotiations going on for many months, during which time the Iraqis learned all they could about the process from its French developers. Finally, the Iraqis backed out, saying the French wanted too much money. The Iraqis then bought patent information, chemicals, and equipment—none of which was controlled—and began developing the process on their own. "It was all creative and legal," Kay said.

The technology acquisition method was a "classic" one for the Iraqis, Kay added. "They would enter into contract negotiations with a country and go almost up to signing a contract, gathering all the information they could. Then they would back out at the last minute and use the information to develop their own process."

According to Kay, before the Gulf War, Iraq had built two generations of prototype chemical enrichment plants and was preparing to step up to initial, pilot-scale industrial production. The IAEA's Zifferero, however, believes that the country did not advance quite this far.

The other enrichment methods illustrate

two other key aspects of Iraq's PC-3 program: the EMIS effort was mostly homegrown, though illicit acquisitions were made and the undertaking benefited greatly from information available in the open literature, whereas the centrifuge program was built entirely around imports of parts, materials, equipment, and designs, most obtained clandestinely. Both the centrifuge development program and the experimental EMIS program were based at a research complex 10 km south of Baghdad. This complex, at Al Tuwaitha, was the centerpiece of the Iraqi nuclear research effort.

It was at Tuwaitha, for example, that the country's Soviet and French reactors had been installed. Although it did not have a supercomputer, which would have been invaluable for simulations and other studies, Tuwaitha was well equipped with 80386-based personal computers and a few larger machines, including a NEC 750 mainframe and software for solving hydrodynamic equations in the presence of shock waves—a useful capability for nuclear weapons design.

A VERY MESSY AFFAIR. The EMIS program surprised not only the IAEA, but Western intelligence agencies. With this technique, a stream of uranium ions is deflected by electromagnets in a vacuum chamber. The chamber and its associated equipment are called a calutron. The heavier U-238 ions are deflected less than the U-235 ions, and this slight difference is used to separate out the fissile U-235. However, "what in theory is a very efficient procedure is in practice a very, very messy affair," said Leslie Thorne, who recently retired as field activities manager on the IAEA action team. Invariably, some U-238 ions remain mixed with the U-235, and the ion streams can be hard to control.

The two different isotopic materials accumulate in cup-shaped graphite containers. But their accumulation in the two containers can be thrown off wildly by small variations in the power to, and temperature of, the electromagnets. Thus in practice the materials tend to spatter all over the inside of the vacuum chamber, which must be cleaned after every few dozen hours of operation.

Hundreds of magnets and tens of millions of watts are needed. During the Manhattan Project, for example, the Y-12 EMIS facility at Oak Ridge in Tennessee used more power than Canada, plus the entire U.S. stockpile of silver; the latter was used to wind the many electromagnets required (copper was needed elsewhere in the war effort).

Mainly because of such problems, U.S. scientists believed that no country would ever turn to EMIS to produce the relatively large amounts of enriched material needed for atomic weapons (although calutrons are still used in scientific research and to produce small quantities of isotopes for medical and industrial uses). Nearly all of the information needed to build and operate calutrons, including the key U.S. patents, has been declassified since the end of World War II.

Among the more explicit sources that can be safely assumed to have been used by Iraqi scientists are: *Atomic Energy for Military Purposes*, by Henry D. Smyth (Princeton University Press, 1945); the Progress in Nuclear Energy Series and National Nuclear Energy Series, which together comprise more than 125 volumes of declassified information from the Manhattan Project, published by McGraw-Hill and Pergamon Press in the late 1940s and early 1950s; two volumes on "The Chemistry, Purification and Metallurgy of Plutonium," declassifed by the United States Atomic Energy Commission, Office of Technical Information, in 1960; and "Developments in uranium enrichment," a collection of symposium papers published by the American Institute of Chemical Engineers in 1977.

The discovery of the Iraqi EMIS program had much of the drama of a good spy novel. The first clue apparently came in the clothing of U.S. hostages held by Iraqi forces at Tuwaitha, according to an expert familiar with the investigation. After the hostages were released, their clothes were analyzed by intelligence experts, who found infinitesimal samples of nuclear materials with isotopic concentrations producible only in a calutron. The analysis was not available until after the war, the source said. The U.S. government has not confirmed this account, most of which appeared first in the *Bulletin of the Atomic Scientists* last September.

The real breakthrough, however, came when a young electrical engineer defected in June 1991. The engineer, who worked at the Ash Sharqat site, revealed the existence and extent of the EMIS program to U.S. intelligence. However, according to news reports at the time, the defector also said that the Iraqis had managed to produce 40 kg of bomb-grade material and that Ash Sharqat survived the war unscathed. Both statements are inconsistent with subsequent IAEA findings; the third IAEA inspection mission to Iraq found that "most of the [Ash Sharqat] facility was destroyed."

> Nearly all of the information needed to build calutrons has been declassified since World War II

THE 'LIVING DINOSAUR.' During the first inspection mission, from May 15–21 of last year, much of Tarmiya's equipment and high-power electrical gear puzzled inspectors. Photographs of it were shown to John Googin, a veteran of the Manhattan Project and the Y-12 facility, which is still at Oak Ridge. Googin conclusively identified the equipment as EMIS components.

"Suddenly we found a live dinosaur," said Demetrius Perricos, deputy head of the IAEA's Iraq action team.

On June 28, during the second mission, IAEA inspectors were denied access to a site at Fallujah. Climbing a water tower, they saw a convoy of nearly 100 Iraqi tank-transporter trucks carrying equipment out the back gate of the site. The inspectors were able to photograph the convoy before Iraqi soldiers fired warning shots in their direction; when enlarged, the photographs showed that the trucks were carrying calutron parts. The Fallujah episode was the second in which inspectors were denied access to a site; both sites were suspected of harboring equipment from Tarmiya and Tuwaitha.

The inspectors believe Iraq was trying to hide as much of its equipment as possible in the desert, where it could be recovered after the intensive inspections ceased. Indeed, numerous giant calutron parts have been found buried in the desert sands at sites west and north of Baghdad.

A NEW MANHATTAN PROJECT. The EMIS program was headed by Jaffar Dhia Jaffar, a British-educated scientist who had a background in particle accelerators and who had worked at the European Center (now Organisation) for Nuclear Research (CERN) in Geneva. Jaffar, who IAEA investigators believe also directed the overall PC-3 program, is "a good physicist, a capable manager, and a great motivator of people," according to Zifferero.

It was in his conception of the Iraqi EMIS program that "Jaffar shows he has a very original mind," Thorne said. For example, where the Manhattan Project required extensive manual adjustment of the ion beams, Jaffar planned to bring the process into the computer age. Computer rooms had been planned for both Tarmiya and Ash Sharqat, from which the process would have been automated. Better control of the beams would have in turn obviated the need for the constant, laborious cleaning work associated with the process.

As in the Manhattan Project, the PC-3 program had developed two types of calutrons, a large A type to enrich the uranium from its natural level, and a smaller B type to further enrich it. Iraqi nuclear scientists told the IAEA that the A type was to bring the enrichment to 3 percent U-235, and the B type to 12 percent. Zifferero doubts that account, noting that 12 percent is a "strange" value, too high for power production and too low for weapons making.

Documents recovered by the IAEA show that a total of 90 calutrons, 70 type A and 20 type B machines, were to have been installed at Tarmiya. But when the site was

(Continued on p. 63)

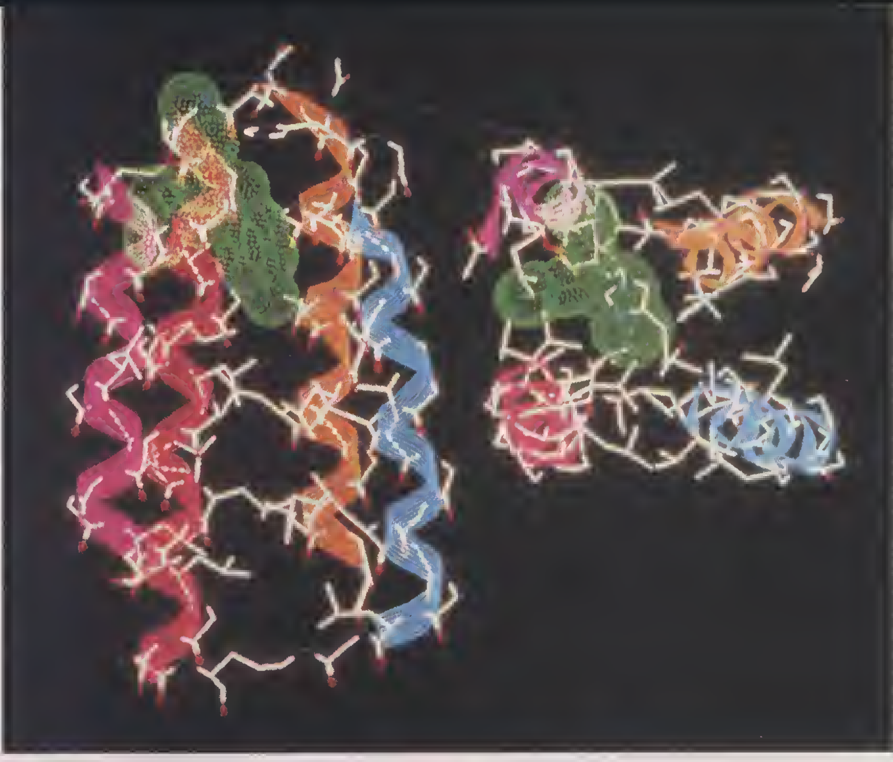
IEEE SPECTRUM

FOCUS REPORT AND GUIDE TO

ENGINEERING WORKSTATIONS

COVERING: ■ NEW FEATURES ■ ADD-ON BOARDS
STORAGE AND BACKUP SYSTEMS ■ GRAPHIC ADAPTERS
NETWORK MANAGEMENT SOFTWARE ■ AND MORE

NEW! SURVEY OF USERS



FOCUS REPORT AND GUIDE TO

ENGINEERING WORKSTATIONS

- Defining terms
- User survey
- Vendor survey
- Add-ons and peripherals
- ICs' impact
- Network management software
- To probe further
- Editorial and advertisers' index

Gadi Kaplan Senior Technical Editor

The global economy may be at a low ebb, but the worldwide market in workstations seems to be growing. International Data Corp., a market research firm in Framingham, Mass., estimated the size of the market in these machines for 1991 was more than US $8400 million, as compared to about $7400 million in the previous year.

Undoubtedly, the engineering, scientific, and even the business communities see workstations as vital tools in today's competitive environment. In a survey commissioned by *IEEE Spectrum* across a sample of the IEEE membership, over half of the respondents reported that their engineering departments used workstations for business purposes. Electronics engineering, however, is the dominant use [p. 30].

The survey pinpoints the most popular software applications and the extent to which client/server environments are used rather than stand-alone workstations. It was conducted for *Spectrum* by Erdos & Morgan, a research firm in New York City.

Another article deals with packages of network management software for networked workstations, part of the trend toward distributed computing [p. 55]. And a box is devoted to X terminals, a player of growing importance in networked workstation environments [p. 42].

The rest of the features cover workstation systems [p. 38], add-ons and peripherals [p. 46], and ICs' impact on workstation design [p. 52].

Representative products and packages are tabulated in four sections of this report. Vendors were asked to submit a representative product from among several they might have introduced between March 1, 1991, and Feb. 29, 1992. However, significant earlier products are also included.

Note that the add-on and peripherals section lists only products from vendors not offering complete workstation systems. All the same, as the most extensive table in the entire report, it covers hardware accelerators and coprocessors, interface and adapter boards, storage and backup systems, input devices, and such output systems as high-resolution monitors, graphics printers, pen plotters, and scan converters.

To acquaint themselves with the terminology, readers may first peruse the defining terms [p. 28]. Sources for in-depth study appear in "To probe further" [p. 59]. Finally, a vendors' index includes all tabulated products plus an untabulated list of X terminal vendors as well as an advertisers' index [p. 60].

When Are You Done Simulating?

A. After You Build Your Model

Start modeling with **SystemBuild™** – an easy-to-use graphical, block diagram editor. Add libraries for linear, nonlinear, continuous, discrete, multi-rate and hybrid systems. You get the most flexible modeling tool available.

B. After You Design and Simulate the Controller

MATRIX$_x$®/SystemBuild are already being used for control design and simulation in automotive, aerospace, and defense companies throughout the world. From gas engines to jet engines — from advanced steering to satellite attitude controls, SystemBuild produces fast and accurate simulation results.

C. After You Deliver a Working Prototype

Test your designs with the **AC-100™** using actual sensors and actuators just minutes after simulating. **AutoCode,™** our patented automatic code generator, converts your SystemBuild block diagrams into C, Fortran, or Ada source code. The code is automatically downloaded and run on our multi-process, real-time controller.

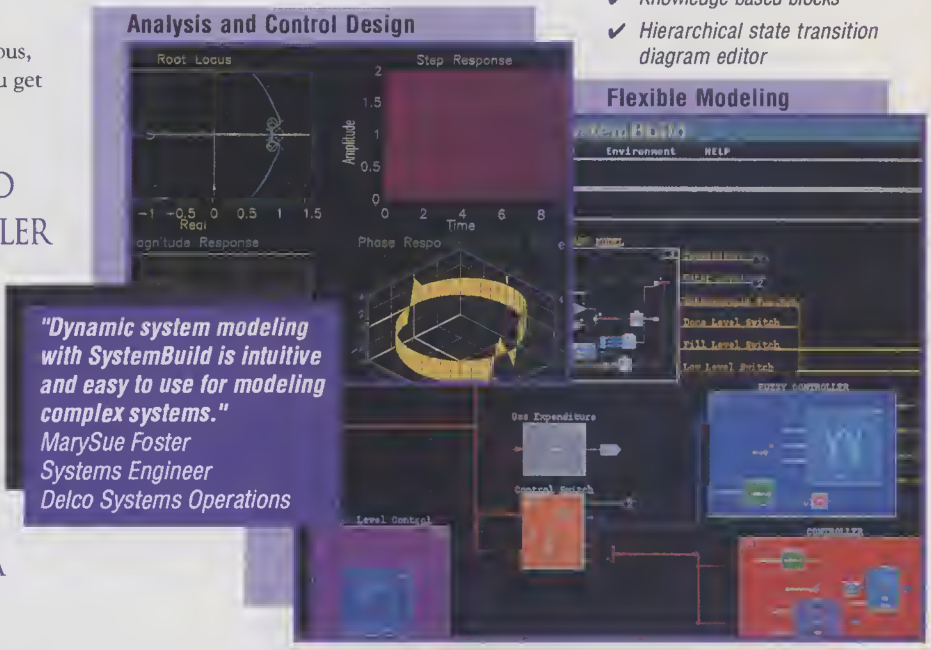
D. All of the Above Call 800.932.6284 for Your Free Demo Diskette.

The MATRIX$_x$ family offers the right tools for each job. Available separately or in application bundles on most UNIX and VMS workstations.

Simulation on workstations starting at under $10,000*.

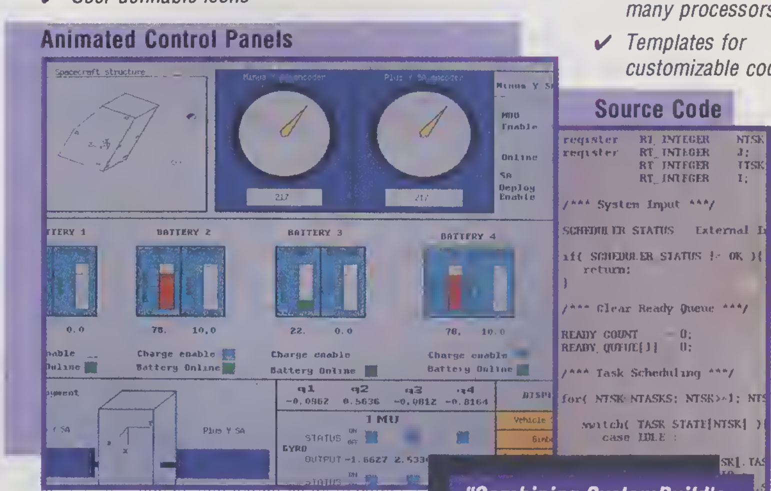
- ✔ *Interactive Root Locus, step response, Nyquist, Nichols, & Bode plots*
- ✔ *Model reduction, system identification, optimization, H∞, LQG/LTR*

- ✔ *SISO & MIMO systems*
- ✔ *Fuzzy logic modeling*
- ✔ *Knowledge-based blocks*
- ✔ *Hierarchical state transition diagram editor*



- ✔ *Interactive or real-time nonlinear simulation*
- ✔ *Strip charts, dials, gauges, switches*
- ✔ *User definable icons*

- ✔ *Retargetable to many processors*
- ✔ *Templates for customizable code*



Enhanced PC Version MATRIX$_x$/SystemBuild

- New mouse-driven graphical block diagram editor
- Extended memory support for large systems modeling

integrated systems inc.

3260 Jay St., Santa Clara, CA 95054
Tel: (408) 980-1500 • Fax: (408) 980-0400

* U.S. prices only. International prices may vary.

Simulate it. Control it. Deliver it. All with One Family of Tools. MATRIX$_x$

Circle No. 201

Defining terms

Agent: part of the distributed management system that resides with the managed objects and represents them to the manager system.

Bridge: a system that uses the bottom two OSI layers to interconnect similar local-area networks (LANs). (See also gateway, OSI, router.)

Cache: a high-speed memory, residing logically between a central processing unit (CPU) and main memory, for holding data and/or instructions the CPU is most likely to need soon.

Command-line interface: an interface between a computer and user requiring the user to type in an alphanumeric command to make the computer perform a task.

Complex–instruction-set computer (CISC): a traditional computer with complex addressing modes whose CPU is designed to run many, often lengthy built-in instructions that support high-level languages. (See also reduced–instruction-set computer.)

Distributed system: a system in which physically distant computing resources can operate efficiently as a single logical entity.

Distributed Management Environment (DME): a set of requirements and applications developed by the Open Software Foundation as an infrastructure for distributed systems.

Extended Industry Standard Architecture (EISA): an extension of the ISA bus (for 80386 and later processors) that provides upward compatibility with earlier ISA systems.

Framework: a modular set of common services that permits applications to be consistently called and controlled.

Gateway: a system that uses all seven OSI layers to interconnect dissimilar local-area networks with different high-level protocols.

Industry Standard Architecture (ISA): the name given to the bus architecture developed by IBM Corp. for the AT version of its personal computer. (See also Extended Industry Standard Architecture.)

MFlops: millions of floating-point operations per second.

Management information base (MIB): a set of objects used for managing the resources of a distributed system.

Micro Channel Architecture (MCA): a proprietary architecture used by IBM Corp. for 80386 and higher processors.

Multichip module (MCM): a small package of ICs bonded directly to a special substrate that allows high-speed transmission.

Object: a description of the resource being managed; objects may range from simple hardware devices to complex software systems.

Open Systems Interconnection (OSI): a widely adopted model of a computer network architecture promulgated by the International Organization for Standardization that divides network functions into seven layers.

Programmatic interface: the calls a program makes and the parameters it passes to request service from another program.

Reduced–instruction-set computer (RISC): extremely regular, easily pipelined computer in which the instruction set is simplified and minimized.

Router: a system that employs the bottom three OSI layers to interconnect dissimilar LANs. (See also bridge, gateway.)

Server: a processor that provides a network with a specified service, such as disk storage.

Simple network management protocol (SNMP): a protocol used to manage and monitor networks based on the transmission control protocol/internet protocol.

Structure of management information (SMI): a specification of the way in which objects in a management information base relate to one another.

Transmission control protocol/internet protocol (TCP/IP): an internetworking standard for OSI levels 3 and 4.

Track ball: a stationary computer-input device with a movable ball.

Transputer: a microprocessor with internal RAM and communication links to other similar microprocessors to facilitate the design of parallel-processing computers.

X/Open System Management (XSM): the X/Open consortium's management model, which includes interfaces to communications, data-storage, and other management services.

X/Open management protocol (XMP): the programming interface adopted by the X/Open consortium for system management.

The user's view

In a selected sample of its readers, IEEE Spectrum *found that more than half of the respondents are using workstations*

What are workstations used for most? Which types of application software are in heaviest demand? Which brands of workstations and which operating systems are preferred? What are the criteria for a "good" workstation, and how often do famous brands fail?

Answers to these and other questions have been attempted in a study of *IEEE Spectrum* subscribers' opinions on workstations, which was completed in January, and in ongoing research by Reliability Ratings Inc., Needham, Mass. This company specializes in the compilation and reporting of reliability data on workstations and such peripherals as magnetic-tape and disk drives, memory systems, monitors, printers, and communications hardware.

Conducted by Erdos & Morgan Inc., a leading market research organization located in New York City, the *Spectrum* study covered 1500 engineers picked at random from selected categories of *IEEE Spectrum* subscribers in the United States. They included 1200 from manufacturing, utilities, and government and military organizations, 150 from R&D laboratories, and 150 from universities.

EE LEAD. Workstations are in wide use among the 49.1 percent who responded to the *Spectrum* study's questionnaire. At any rate, over half of the respondents (54.8 percent) are currently using workstations, and more than two thirds of these have been using the equipment for three years or more. The leading area of application is electronics engineering, mentioned by over half the nearly 400 who replied to the relevant section in the questionnaire. Next came scientific use and publishing, each cited by about a quarter of the respondents [Fig. 1].

The most common area of application software, possibly because it is the least specialized? Of course, it's word processing, as reflected by nearly four-fifths of 388 workstation users. Trailing that are communications software (49.2 percent) and computer-aided design, manufacturing, and engineering (CAD/CAM/CAE) software (45.6 percent) [Fig. 2, top]. System and software design are champions among design disciplines employing workstations—each noted by over half of nearly 300 respondents [Fig. 2, middle].

To remove any doubt, the use of workstations for business purposes has a high profile in the engineering and scientific community—over half of 685 respondents confess to such use by themselves or their departments. Here again word processing rules supreme—as is documented by three-quarters of the respondents [Fig. 2, bottom].

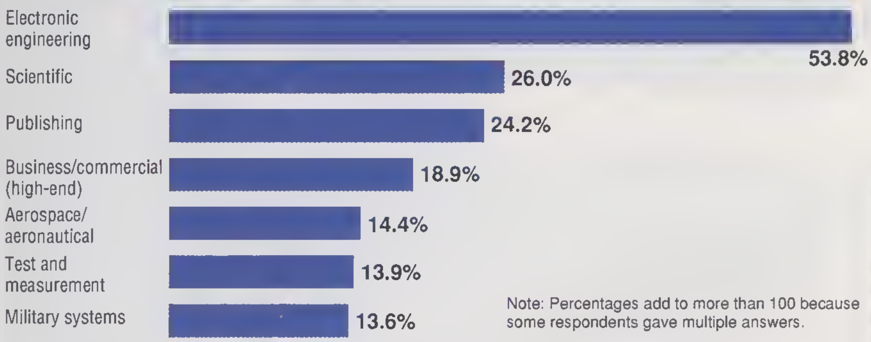
USER FRIENDLINESS. Ease of use is an important attribute—63 percent out of more than 400 respondents believe so. The space a workstation occupies, on the other hand, does not matter much, according to more than 43 percent of the respondents [Fig. 3].

These are only two of the considerations likely to influence the decision whether, which, and how many new workstations should be bought by year-end. Almost 60 percent of nearly 400 respondents estimate that their companies will purchase an average of nearly 90 workstations per company. More than 15 percent estimate a purchase of 250 or more units [Fig. 4]. However, the majority—more than 60 percent—estimate anywhere from 1 to 50 units, with the median being nearly 26 units per company.

As for the brands used, IBM Corp.'s platforms are the most pervasive, serving nearly 43 percent of 400 respondents. Sun Microsystems Inc. runs close behind at 40 percent and Apple Computer Inc.'s Macintosh at 29.3 percent. Which IBM model is most widely used? Nearly 40 percent of the 400 respondents to this question reported using IBM 386- or 486-based PCs; only 6.3 percent employ the RS/6000 workstations [Fig. 5, top]. Do these numbers reflect the preferences of those involved in buying or leasing workstations for their companies? Apparently not, according to the survey's returns. Here Sun is a clear winner, with about one in three of nearly 360 respondents preferring its brands, versus the one in five favoring IBM or Apple's

Key application areas

Respondents involved in, % (base = 396)



Note: Percentages add to more than 100 because some respondents gave multiple answers.

[1] About 54 percent of nearly 400 IEEE members use their workstations for electronics engineering, and fewer use them for scientific computing, publishing, and business.

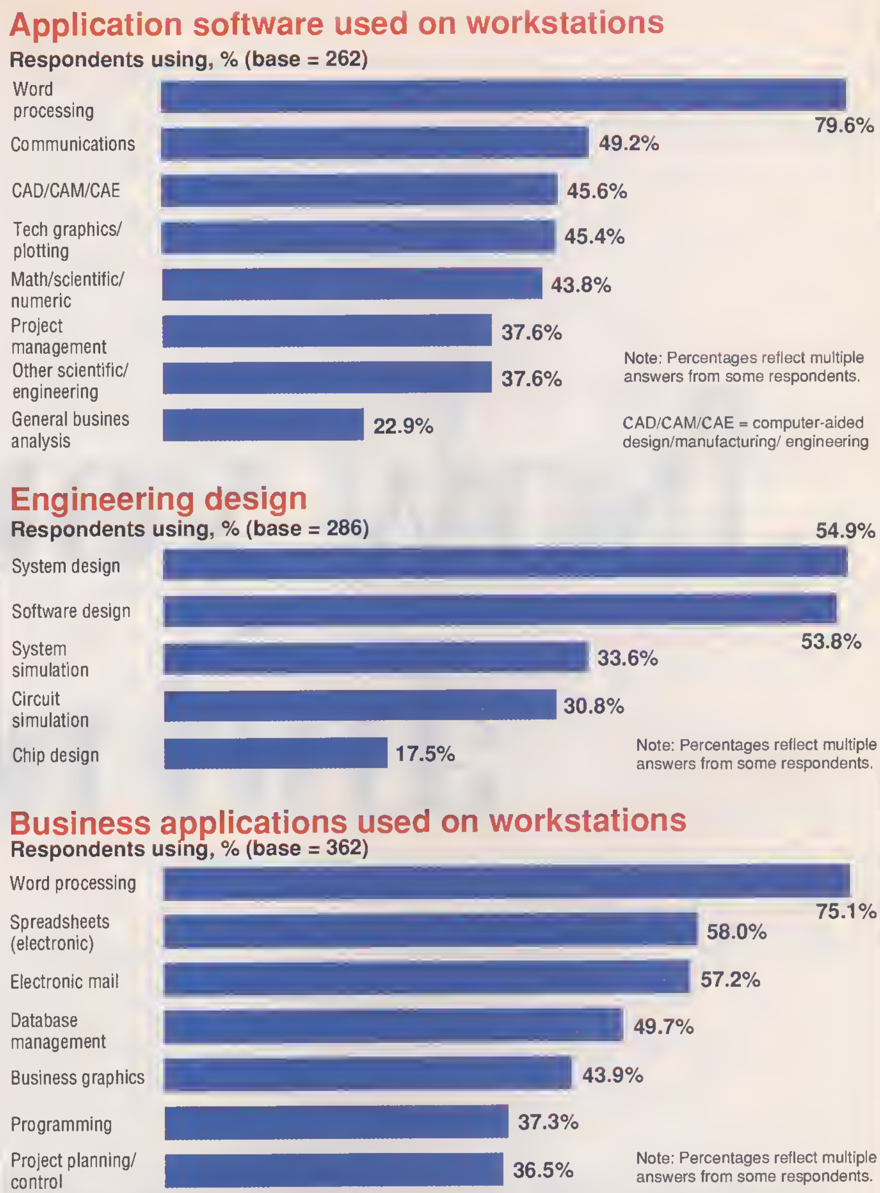
Workstation failure statistics

Company	Model	Accumulated run time, hours	Mean time between failures, hours	Annual failure rates	
				System	Central processing unit
Digital Equipment Corp.	DEC 5000 -120	322 848	35 872	24.08%	0 %
Hewlett-Packard Co.	HP 9000 -425	880 500	58 700	14.72%	3.93%
Sun Microsystems Inc.	Sparcstation/SLC	1 786 446	40 601	21.28%	15.96%

Source: Reliability Ratings Inc., Needham, Mass.

Gadi Kaplan Senior Technical Editor

 0018-9235/92/$3.00©1992 IEEE



[2] Word processing, communications, and CAD/CAM/CAE—computer-aided design, manufacturing, and engineering—are the leading types of application software used (top). System and software design are among the leading engineering design areas assisted by workstations (middle). Word processing tops the list of the business applications (bottom).

Macintosh models [Fig. 5, bottom].

The picture is less clear cut with operating systems. On the one hand, DOS—the traditional operating system in not only IBM platforms but also in a whole slew of IBM compatibles—has nearly 60 percent of almost 400 respondents using it. On the other, Unix and Sun/OS (also a Unix system) are used by more than 45 percent of the survey's respondents, even when considering multiple answers by the same users. Next comes Macintosh with 28 percent [Fig. 6].

Looking ahead 10 years, which processor design is preferred for workstations? Here the reduced-instruction-set computer (RISC) is clearly preferred to the complex-instruction-set computer (CISC), which predominates in today's designs. Most respondents (65 percent of nearly 320 respondents) are partial to RISC, as compared to 15 percent who prefer CISC technology and 20 percent who are undecided.

The higher performance of the RISC design is frequently given as the reason for this preference. "As speeds increase, the execution time of a large number of RISC statements will be insignificant, whereas the complexity of CISC programming will be too limiting," noted an engineer who has used workstations for industrial control and simulation for more than five years.

Others, though, had reservations about RISC. Lack of third-party software was one drawback cited. It is "not software compatible with a PC," reported an engineer in a medium-sized company (one with fewer than 100 workstations installed). It "only runs Unix," which is "*very* user unfriendly," wrote another at a fairly large company (more than 10 000 employees) in the Ann Arbor, Mich., area. RISC "does not improve heavy I/O on CPU-intense jobs," commented yet another, who belongs to a company in San Jose, Calif.

Not the least concern is the cost of RISC-based platforms. "Overall, platforms where RISC is implemented can often be very expensive compared to CISC," wrote an engineer in a company with over 500 workstations.

And what about the networking and client/server environment, as opposed to standalone use of workstations? About 80 percent of nearly 400 respondents reported that their workstations are networked. As for a client/server environment, according to the survey, about 60 percent of the users' workstations are connected to a server (basically a large mainframe or minicomputer or a workstation acting as a shared resource for several users—a database, for example). "File sharing and larger storage" were cited as advantages over a standalone configuration by one respondent in a company that has between 100 and 249 workstations. Reliability, however, is a main concern. "A dead server can shut down a whole group of stations," he noted. One "must rely on a server specialist to solve problems," commented another engineer working in a company focusing on control system design and instrumentation. Reduced security and processing speed are among disadvantages cited by yet another engineer.

RELIABILITY SCRUTINIZED. The key role played by workstations in their professional lives is likely to make engineers very careful when selecting new units for purchase, particularly vis-à-vis reliability—obviously, the higher the mean time between failures, the more favored the unit. Mean time between failures is defined by Reliability Ratings as the total accumulated run time divided by the number of hard failures.

For example, by mid-February, Reliability Ratings had accumulated data from millions of hours of run time. The data focuses on what the company defines as "hard" failures—those that render the equipment inoperable and require repair by the customer or the vendor's service person. "Every failure is a problem, but not every problem is a failure," Kevin Beam, vice president at Reliability Ratings cautioned *Spectrum* in a telephone interview.

Failure rates are recorded for systems (that is, a basic workstation configuration including the CPU and such peripheral equipment as memory, disk drives, and monitors) and also for the CPU alone. (In the future, peripherals will be monitored individually.)

Reliability Ratings looks at failure rates, which it defines as the annual number of failures (of a given workstation model) per year divided by the number of units in the sample monitored. The number of units is "annualized," or multiplied by a correction factor for those units that have been

Now you can and not get

Introducing new RISC System/6000 POWERstations

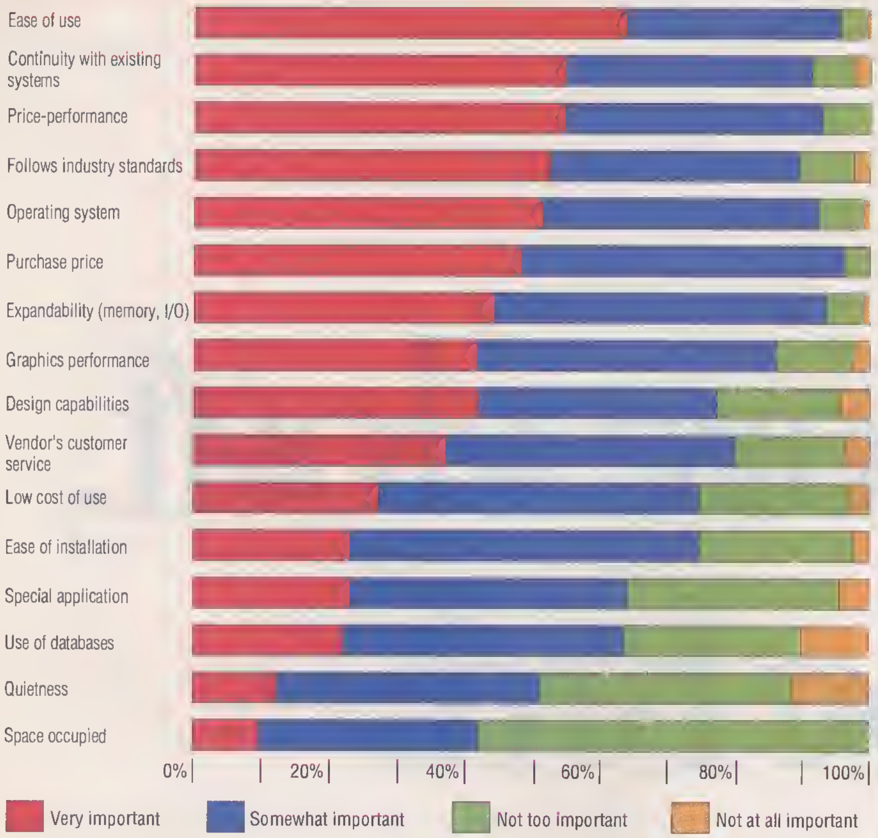
If you're interested in open systems but don't want to suffer the slings and arrows of outrageous prices, IBM is about to hit you where you live. The RISC System/6000™ POWERstation 220 gives you more wallop for your money, while delivering a hefty 25.9 SPECmarks.™ That's compared to the SUN IPC's™ 13.4 SPECmarks and the DEC5000's™ 17.8.

Model	Entry Grayscale Workstation**	Entry 8-bit Color Workstation†
IBM 220W	$7,185	$9,995
HP 705/710	$8,415	$14,065

Scientists see stars. CASE users can start with a grayscale workstation with a paging disk for just $7,185. If it's CAD clout you're after, you can get a workstation specially outfitted for mechanical design—with 2D color graphics and 400MB of fixed disk storage—for only $9,995. All models in the POWERstation 220 series come with two expansion

*In Canada, call 1 800 465-1234. **16MB, Paging Disk, Display, Operating System, Graphical User Interface. †16MB, 400MB Disk, Display, Operating System, Graphical User Interface. IBM is a registered trademark and RISC System/6000 is a trademark of International Business Machines Corporation. SPECmark is a geometric mean of the ten SPECmark tests and is a trademark of Standard Performance Evaluation Corporation. All SPECmark figures listed are as published by their respective manufacturers. All prices listed are MSRP. Remarketer prices may vary. IPC is a trademark of Sun Microsystems, Inc. DEC5000 is a trademark of Digital Equipment Corporation. UNIX is a registered trademark of UNIX Systems Laboratories. HAGAR THE HORRIBLE Character(s) © 1992 King Features Syndicate, Inc. ©1992 IBM Corp.

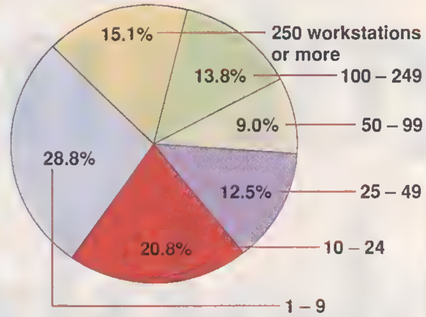
Workstation purchase criteria (base = 403 to 421)



[3] Ease of use is considered "very important" by most respondents. Features such as quietness and the space occupied by a workstation are discounted by a large number of respondents (50 percent or more). Interestingly, when counting individual votes (not shown), purchase price came sixth among the "very important" entries with its 200 votes, as compared to ease of use at the top with 266.

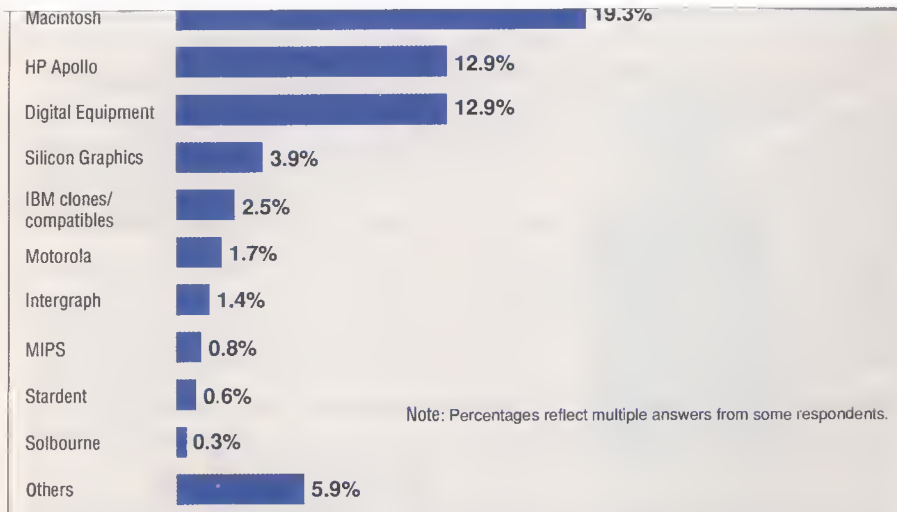
Number of workstations that companies plan to buy

Respondents reporting, % (base = 399)



[4] Far from being saturated, the workstation market is steadily growing—more than 60 percent of 400 respondents estimate that their companies will buy anywhere from 1 to 49 workstations this year alone.

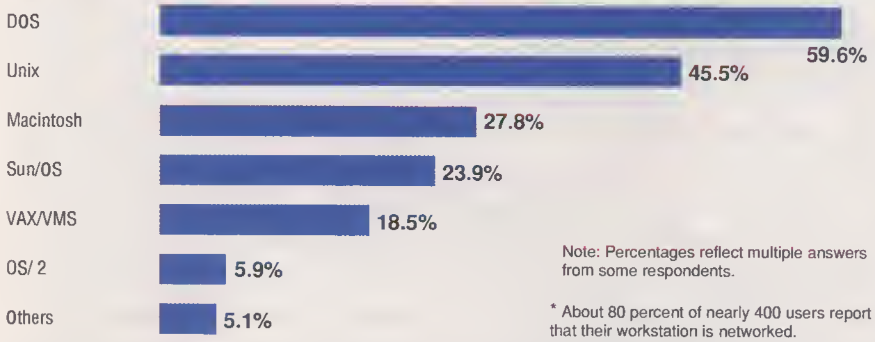
Focus Report: Workstations



[5] IBM, Sun, and Apple Computer's Macintosh are the leading brands presently in use, with IBM 386- and 486-based PCs alone used by nearly 40 percent of the respondents and RS/6000 by 6.3 percent (top); but Sun seems to be the preferred brand for future purchases (bottom).

Operating systems predominating in workstations*

Respondents using, % (base = 389)



* About 80 percent of nearly 400 users report that their workstation is networked.

[6] The DOS operating system is used by about 60 percent of workstation users, with Unix and Sun/OS (also a Unix system) employed by more than 45 percent. (Caution: because of multiple answers the two sets of numbers are not mutually exclusive.)

›r or CPU combined and only PU alone [see table, p. 30]. In › units accumulated a total of s in the last 12 months, or 5210 ı the average (equivalent to a ın, day and night, during 7.24

lts are consistent with average eliability data collected thus far, They also reflect better relia- PU level than that obtained in user systems, in which a sin- nicomputer serves several led.

lably, users' response to the ›orts has been "very, very ccording to Beam. Workstation ›ore critical, he points out, par- e recorded data do not favor

›le, this reliability data collec- prove valuable to both design- of workstations, and it may ribute, albeit indirectly, to fu- lesigns. ◆

AHEAD: RELIABILITY AND MORE

How reliable are the workstations in your department? Are they being upgraded? Is distributed computing an important element in your company's workstation environment? We plan to address these and related questions in a forthcoming update.

Your immediate, faxed or mailed response to all or part of the following questions would help. (Check one box as applicable, adding explanations on a separate sheet, as needed.)

Reliability:

1. In my department, the estimated percent of workstations that are down at any one time averages less than 1% □; 1–5%□; 5–10%□; higher than 10%□.
2. Do you have other ways of assessing workstation reliability? Please list them.

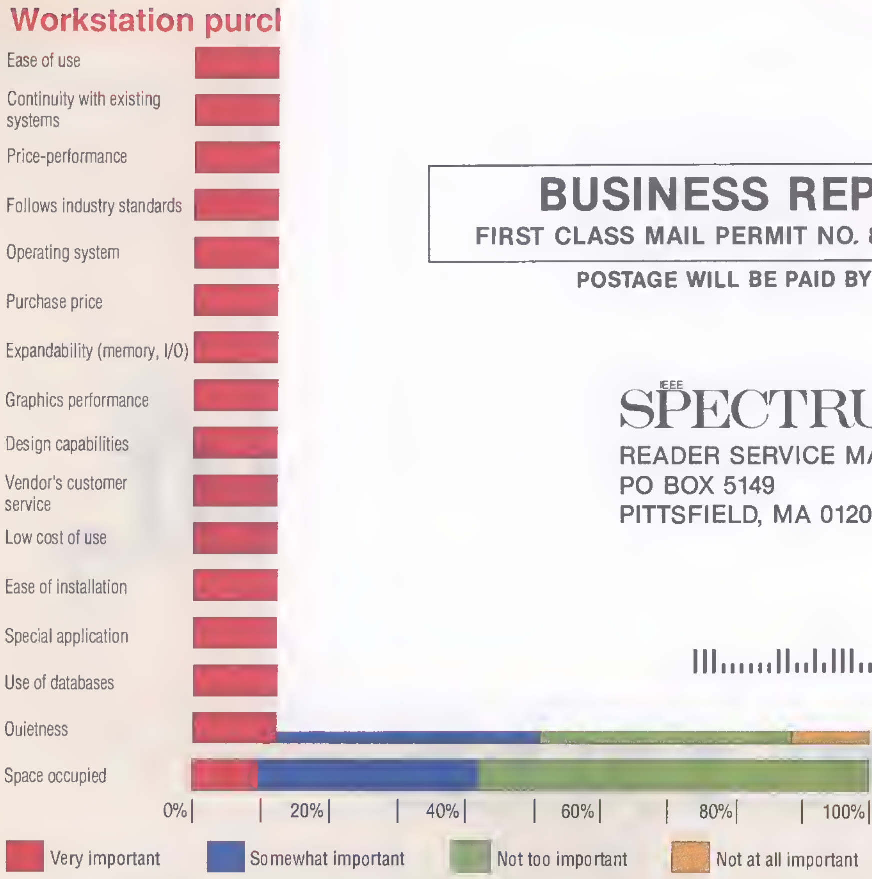
Upgrading:

3. In my department, the estimated percent of workstations that have been upgraded in the last 12 months by the addition of new boards (more powerful CPUs, coprocessors, graphics processors, and so on) is under 5%□; 5–15%□; 15–30%□; more than 30%□.
4. Is upgrading preferable to purchasing or leasing new models? Yes□ No□. Explain.

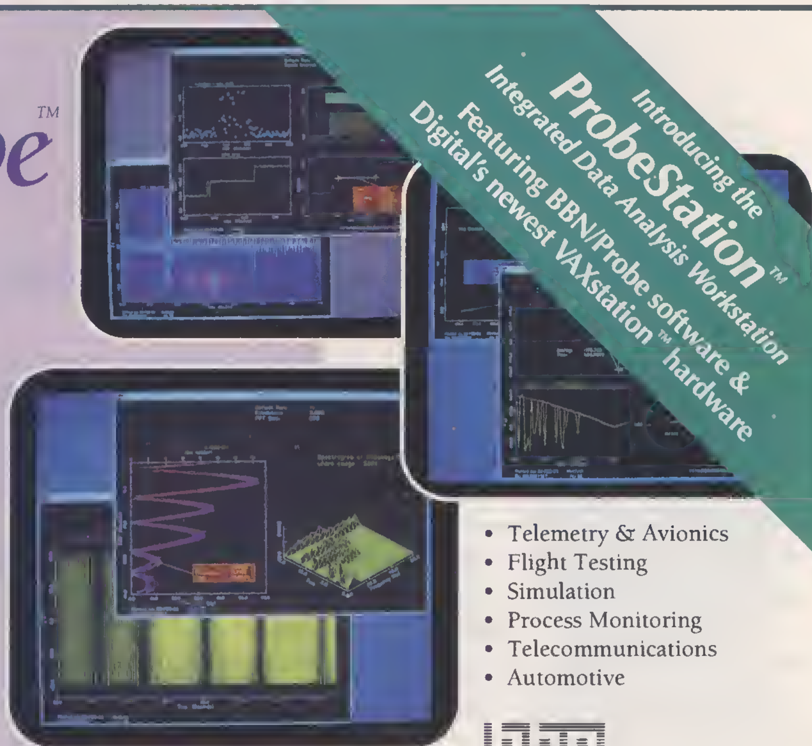
Distributed computing:

5. The estimated percent of workstations in my department that are operating in a true distributed computing environment is less than 5%□; 5–10%□; 10–25%□; 25–50%□; more than 50%□.
6. The effect of distributed computing on my department, on a scale of –10 (very obstructive) to 10 (very helpful), (0 being neutral) is __________.
7. The number of X terminals in my department as a percent of the number of workstations is an estimated 10% or less□; 10–25%□; 25–50%□; more than 50%□.
8. The usefulness of X terminals on a scale of 0 (not useful) to 10 (most useful) is __________ Please explain.

Please respond, indicating your name, title, company, address, and telephone and fax numbers, to *IEEE Spectrum* [WORKSTATIONS FOLLOWUP], by fax (212-705-7453) or by express mail to 345 East 47th St., New York, N.Y. 10017. We will use your name only with permission. —*Ed.*



[4] Far from being saturated, the workstation market is steadily growing—more than 60 percent of 400 respondents estimate that their companies will buy anywhere from 1 to 49 workstations this year alone.



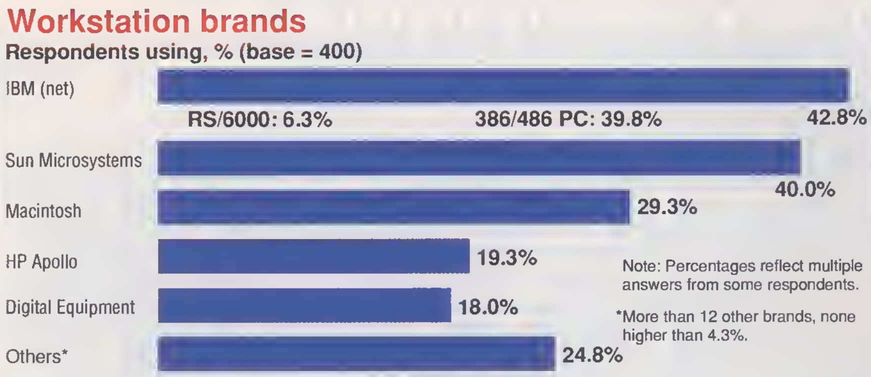
installed during only part of a year.

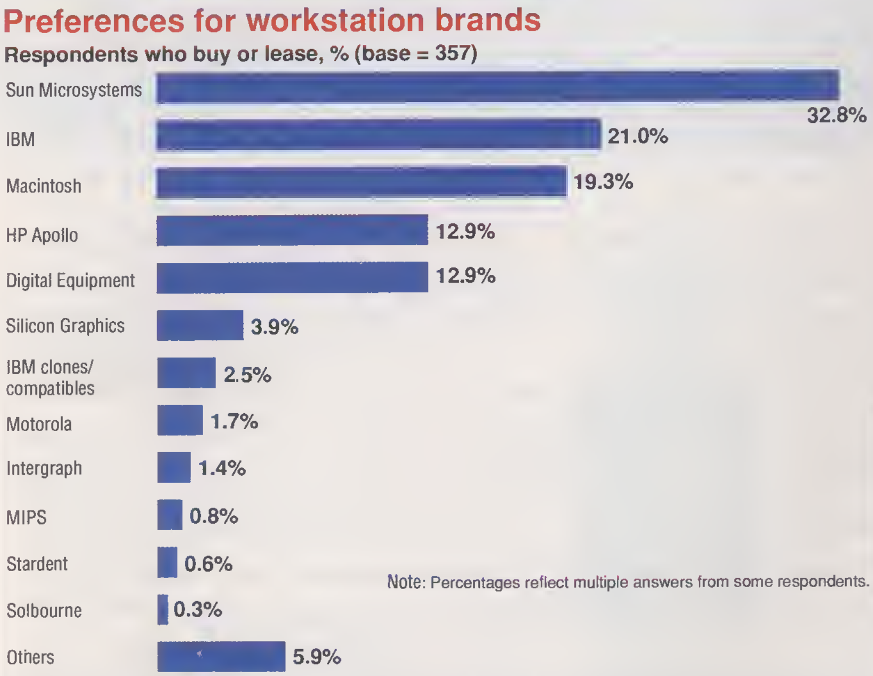
For example, according to Beam, an annual system failure rate of nearly 15 percent was recorded for HP9000-425 workstations, but only 4 percent for the CPU alone. In other words, if each workstation were up and running for a full year, then for every 100 workstation systems during the 12 months ending on Feb. 13 (when the data was taken) there were 15 failures in the memory, disk drive, monitor or CPU combined and only four on the CPU alone [see table, p. 30]. In actuality, 169 units accumulated a total of 880 500 hours in the last 12 months, or 5210 hours each on the average (equivalent to a continuous run, day and night, during 7.24 months).

These results are consistent with average workstation reliability data collected thus far, Beam noted. They also reflect better reliability at the CPU level than that obtained in typical multi-user systems, in which a single superminicomputer serves several users, he added.

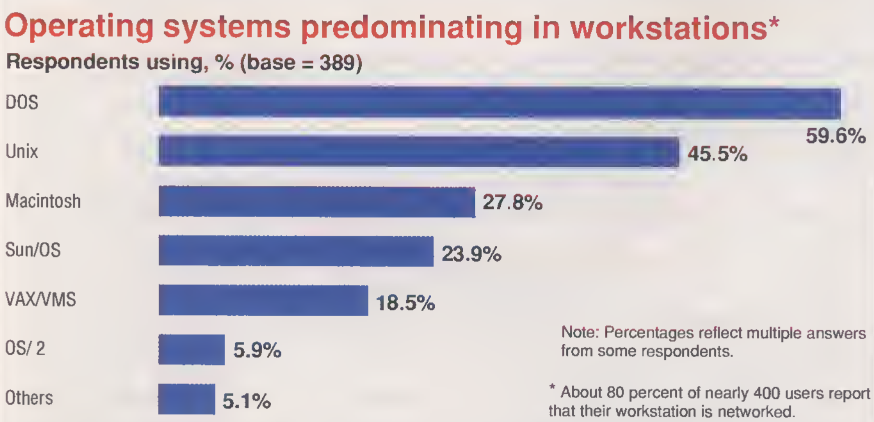
Understandably, users' response to the reliability reports has been "very, very favorable," according to Beam. Workstation vendors are more critical, he points out, particularly if the recorded data do not favor them.

On the whole, this reliability data collection is likely to prove valuable to both designers and users of workstations, and it may very well contribute, albeit indirectly, to future system designs. ◆





[5] IBM, Sun, and Apple Computer's Macintosh are the leading brands presently in use, with IBM 386- and 486-based PCs alone used by nearly 40 percent of the respondents and RS/6000 by 6.3 percent (top); but Sun seems to be the preferred brand for future purchases (bottom).



[6] The DOS operating system is used by about 60 percent of workstation users, with Unix and Sun/OS (also a Unix system) employed by more than 45 percent. (Caution: because of multiple answers the two sets of numbers are not mutually exclusive.)

LOOKING AHEAD: RELIABILITY AND MORE

How reliable are the workstations in your department? Are they being upgraded? Is distributed computing an important element in your company's workstation environment? We plan to address these and related questions in a forthcoming update.

Your immediate, faxed or mailed response to all or part of the following questions would help. (Check one box as applicable, adding explanations on a separate sheet, as needed.)

Reliability:

1. In my department, the estimated percent of workstations that are down at any one time averages less than 1% ☐; 1–5%☐; 5–10%☐; higher than 10%☐.
2. Do you have other ways of assessing workstation reliability? Please list them.

Upgrading:

3. In my department, the estimated percent of workstations that have been upgraded in the last 12 months by the addition of new boards (more powerful CPUs, coprocessors, graphics processors, and so on) is under 5%☐; 5–15%☐; 15–30%☐; more than 30%☐.
4. Is upgrading preferable to purchasing or leasing new models? Yes☐ No☐. Explain.

Distributed computing:

5. The estimated percent of workstations in my department that are operating in a true distributed computing environment is less than 5%☐; 5–10%☐; 10–25%☐; 25–50%☐; more than 50%☐.
6. The effect of distributed computing on my department, on a scale of –10 (very obstructive) to 10 (very helpful), (0 being neutral) is ________.
7. The number of X terminals in my department as a percent of the number of workstations is an estimated 10% or less☐; 10–25%☐; 25–50%☐; more than 50%☐.
8. The usefulness of X terminals on a scale of 0 (not useful) to 10 (most useful) is ________ Please explain.

Please respond, indicating your name, title, company, address, and telephone and fax numbers, to *IEEE Spectrum* [WORKSTATIONS FOLLOWUP], by fax (212-705-7453) or by express mail to 345 East 47th St., New York, N.Y. 10017. We will use your name only with permission. *—Ed.*

What the vendors wrought

More power is key as workstations gain central processor chips at 40 and 50 MHz and RAM capacity of 128M bytes and up

More raw power than anyone could have reasonably expected was unleashed by workstation manufacturers during the last 12 months. And the amount of memory that can be addressed—up to 128M bytes for a number of models and even higher for others—certainly adds to the variety of tasks that can be performed. What's more, the power did not just go into desktop or deskside units, but into portables as well.

Central processing units (CPUs) operating at 33 MHz seemed commonplace, and 40- and 50-MHz chips were not unusual. In most cases, the manufacturers introduced multiple units to their families of machines [see table for details on representative units].

In what it termed its "biggest RISC [reduced-instruction-set computer] System/6000 announcement since the original product launch" two years before, IBM Corp. in late January announced it was expanding the performance of its Unix family of workstations and servers with five new models, and bringing out a host of software offerings. The new Powerstation/Powerserver units range from the under US $7000 desktop Model 220 system built around IBM's first single-chip RISC processor to a new high-end deskside model.

The Model 220 is the lowest-priced RISC System/6000 workstation announced by IBM so far. It can be used as a network-attached diskless or data-less system or as a stand-alone workstation or server. (In a data-less system, the user's data and applications are stored on a server and downloaded to the workstation's disk to be accessed.)

Integrating Ethernet and small computer systems interface (SCSI) capabilities and using IBM's Power Gt1 graphics adapter, the new unit supports monochrome, gray scale, or color. Performance includes a rating of 25.9 Specmarks and 6.5 million floating-point operations per second (MFlops). With 16 Mbytes of memory standard, the Model 220 starts at $6345 for a monochrome diskless system.

Alfred Rosenblatt Managing Editor

In addition, IBM introduced three desktop and two deskside systems, which range up to $64 000 in price. All are based on the company's Performance Optimization with Enhanced RISC (Power) Architecture, and use the Micro Channel bus and AIX/6000, IBM's version of the Unix operating system.

MOVING INTO POSITION. Digital Equipment Corp. spent a busy year positioning itself in the workstation marketplace. It topped off its effort with a 19-product rollout in December that highlighted a personal touch—with the $3995 Personal DECstation 500 Model 20. Built around a 20-MHz MIPS Computer Systems Inc.'s R3000A RISC processor, this diskless entry-level whizzer-for-the-wallet is benchmarked at 16.2 Specmarks and comes with audio, graphics, and expansion capabilities. DEC asserted that it represents "RISC workstation performance and functionality at PC prices."

The new workstation also shared the same built-in upgradability of the other DEC systems—a modular design allowing for higher-speed CPU daughter cards, including MIPS Computer's not-then-yet-announced MIPS R4000 RISC.

Other new DEC products included the company's highest-performing workstations yet: three RISC servers, a 33-MHz CPU ugrade to the existing DECstation 5000/100 series, and assorted graphics boards and peripherals, as well as multivendor hardware and software support programs. All seven hardware products are compatible with the Advanced Computing Environment (ACE): software developed to run on these workstations and servers will run without compilation on future ACE platforms.

(Since the ACE initiative was announced in April 1991, more than 200 companies—system manufacturers, semiconductor suppliers, software developers, and add-in hardware vendors—have agreed to offer compatible systems built around MIPS Computer's RISC processors.)

DEC's highest-performing RISC/Unix workstation was the DECstation 5000, Model 240. Built around a 40-MHz R3000A chip, it handles 32.4 Specmarks at a price starting at $11 995. As it was announced, so were plans for DEC and Microsoft Corp.—two of ACE's nine founding members—to provide Microsoft's newest operating system, Windows NT, on the DECstation 5000 series.

WORKSTATION CLASS. Though the word "workstation" is absent from its product literature, Apple Computer Inc. reached well up into the workstation class with the introduction of its two Macintosh Quadra computers at the Comdex Show in Las Vegas, Nev., last fall. The two PCs represented the company's "largest single jump in computing performance since the introduction of the Macintosh II in 1987." The Quadras are up to twice as fast as the Macintosh IIfx, the company's previous highest-performance system.

The computers are built around the 25-MHz 68040, which incorporates 8K bytes of fast cache memory, a floating-point coprocessor, and a memory management unit. Both units have a minimum of 4M bytes of RAM, an Apple SuperDrive hard disk of 80, 160, or 400 Mbytes (the Quadra 900 can accommodate two), and built-in support for all Apple displays. A video RAM option adds color support for up to 16.7 million colors. Both machines also have built-in support for Ethernet, as well as Apple's LocalTalk, and sound input/output.

RAM can be expanded to 20M bytes on the Quadra 700, which has a base price of $5699, and up to 64M bytes on the Quadra 900, which has a base price of $7199. The Quadra 900 also has five NuBus slots (instead of two as on the Quadra 700), a larger power supply for the plug-ins, and up to four internal SCSI devices.

SPARC ACTION. The Sparc RISC processor saw lots of action in the past year, and not just from its progenitor, Sun Microsystems Inc. Last summer, Sun rolled out several powerful new desktop systems and added features to its Sparcstation family.

Included was the mid-range $11 995 Sparcstation IPX, a desktop accelerated-graphics system with many features of Sun's high-end Sparcstation 2 in a smaller, less expensive package. Sun also unveiled the entry-level monochrome Sparcstation ELC, which has twice the processing power and four times the memory of its predecessor, the Sparcstation SLC. The $4995 workstation offers multiple windows, a high-resolution display, and fast response time.

Both the IPX and ELC workstations are powered by a new Sparc microprocessor that combines integer and floating-point units on a single chip. The 40-MHz IPX processor delivers 24.2 Specmarks; the 33-MHz ELC delivers 20.1 Specmarks. Like other Sun Sparc workstations, the two conform to Sparc Compliance Definition (SCD)

0018-9235/92/$3.00©1992 IEEE

Representative sample of newest workstations

Company	Model	Unit cost, US $	CPU (clock speed)	Operating system	Memory[†] Main, Mbyte	Memory[†] Total cache, Kbyte	Features and comments
Acer America Corp.	AcerPower 486SX	$2195	80486SX/ (20 MHz)	DOS, Unix	2–98	8	Chip upgradable to 25- or 33-MHz 80486DX; ultra-VGA on board (1024 X 768 X 6 pixels noninterlaced)
Apple Computer Inc.	Macintosh Ouadra 900	$7199	68040 (25 MHz)	Macintosh, DDS, DS/2	4–64	8	1M-byte video RAM; keylock, microphone, sound generator
Arche Technologies Inc.	Legacy 486/33	$3398	80486 (33 MHz)	OOS, Windows	64	128	Optional coprocessor; Tower model available
Cetia, a Thomson-CSF subsidiary	Cetia 1000	$14 000	88100 (25 MHz)	Unix V, Lynx OS	32–128	128	1,2, or 4 CPUs; high resolution (1600 X 1200 pixels) and high performance graphics; VME workstation; supports multiprocessing, multiprotocol X.25/ISDN controller and multimedia VME module
Compaq Computer Corp.	Deskpro 486/50L	$11 299	80486DX (50 MHz)	DOS, OS/2, Unix	8–104	256	Advanced VGA, 640 X 480 pixels; 32-bit EISA expansion bus
CompuAdd Computer Corp.	SS2	$6995	Sparc (40 MHz)	Sun/OS 4.1.1	8–64	64	8inary compatible with, and more expandable than, Sparcstation 2; Sun GX graphics option
Control Data Corp.	9108-235	$17 500	R3000A (33 MHz)	Irix	16	64	3-D workstation includes 24 color bit-planes, 16-inch monitor, and 432-Mbyte disk
Copam USA Inc.	486V-33	$2885	80486 (33 MHz)	DOS 5.0	2–32	128	7 hard-drive bays; Weitek coprocessor socket
Data General Corp.	AViiDN AV530	$18 950	88100 (33 MHz)	DG/UX 5.4	16–128	32	Supports dual processors, symmetrical multiprocessing
Oell Computer Corp.	PowerLine 450DE	$5679	80486DX (50 MHz)	Unix, OS/2	4–96	128	With 4M-byte RAM, UltraScan 14C monitor, 100-Mbyte hard drive; upgradable processor design; SmartVu diagnostic display
Oigital Equipment Corp.	Personal OECstation 5000, Model 20	$3995	R3000A (20 MHz)	Ultrix, OSF/1	40	128	CPU on 3 X 5-inch daughter card; ACE compatible; integral audio; two 50-Mbyte/s Turbochannels
Dolch Computer Systems	P.A.C. 486-50E	$9000	80486 (50 MHz)	DOS	4–32	8 primary, 128 secondary	11-inch gas plasma VGA display, 120 Mbyte hard disk drive; optional active-matrix color display
Evans & Sutherland Computer Corp.	ESV 20/33	$60 000	R3000A (33 MHz)	Unix	16–128	64	Very high-performance 3-0 graphics; supports various graphics and communications standards
Hewlett-Packard Co.	HP Apollo 9000, Model 710	$9490	PA-RISC (50 MHz)	HP-UX	16–64	32 (instruction), 64 (data)	Supports renderings; 8-kHz audio capability; supports FOOI, X.25, I8M Token Ring, SCSI; CD ROM
I8M Corp.	Powerstation 220	$6345	PowerRIsc (33 MHz)	I8M AIX	16–64	8 (combined data and Instruction)	Power Gt1 graphics adapter supports monochrome, gray-scale, and color; two expansion slots, diskless capability, integrated SCSI and Ethernet
Intergraph Corp.	IP2430	$18 500	Clipper C400 (33 MHz)	Clix (Unix V.3)	16–128	64 (instruction); 128 (data)	3–6 times taster than earlier IP2020 model; double-buffered graphics; supports all Intergraph CAD/CAM/CAE applications and networking protocols
Laser Digital Inc.	Pacer 486-33E	$6250	80486 (33 MHz)	DOS/Unix	64	256	Socket for Weitek coprocessor; memory on mother board; 8 EISA slots; optional network cards
Mars Microsystem Inc.	Mariner 4i	$8995	Sparc and 80386 (25 MHz)	Sun/OS	8–96	64	Dual processors for simultaneous Unix/DOS operation; Sun compatible; ISA bus
Micro Express	ME 386-40	$1899	am386-40 (40 MHz)	DOS, Unix	4–64	64–256	200-Mbyte disk drive included; up to 1.2-Gbyte drive optional; Hi-Color VGA card; low-radiation monitor
Microway Inc.	486B²T	$12 421	80486 (33 MHz); i860 (40 MHz)	OOS, Unix	16–32	256	Dual processors; includes 16 Mbytes and i860 card providing up to 80 MFlops; 8-slot EISA motherboard
MIPS Computer Systems Inc.	Magnum/33	$9990	R3000A (33 MHz)	RISC/OS, Unix	8	64	—
Mobius Computer Corp.	IPS/2	$10 370	Sparc (40 MHz)	Sun/DS, Solaris 1.0	16–64	64	8undled with X11.4, Motit, Clarity Rapport (spreadsheet, test editor); 100% Sparc compatible per SCD 1.1 test and verification suite by Sparc International
Modgraph Inc.	GX-2486C/33	$6195	80486 (33 MHz)	DOS, Unix	4–32	64–256	Portable system with 8.5-inch Sony color tube; up to 4 expansion slots
NCR Corp.	System 3000, Model 3345	$6135	80486 (33 MHz)	Dos, OS/2, Unix V.4	4–128	8	Dual-ported memory; coprocessor optional; advanced VGA (1024 X 768 pixels) standard; standard SCSI II adapter

1.0, which ensures compatibility with SCD-compliant Sparc systems from other vendors. Both workstations include SCSI, serial ports, Ethernet, and audio capabilities.

For the IPX, Sun's engineers miniaturized the unit's GX graphics accelerator, taking it from a 125 × 150-mm board to a single chip mounted on the CPU board. The ELC packs its components into a convection-cooled CPU board that slides into the rear of a high-resolution, 1152 × 900-pixel, 4-dot-per-millimeter monochrome monitor. The IPX is available in a color model; the ELC, in monochrome only.

With the Sparcstation IPX stealing some of the high-end Sparcstation 2's thunder, Sun, naturally enough, added major enhancements to its old warhorse. These included doubling memory and disk storage, and increasing processing power by 15 percent and graphics performance by up to 10 percent. Thus, for example, the standard Sparcstation 2 offers 32M bytes of main memory (up from 16M bytes), and a faster 424-Mbyte internal disk (instead of a 207-Mbyte disk). Up to 848 Mbytes can fit into the package. Base price of the 24.7 Specmark machine is $15 495.

Another Sparc workstation, one of a number introduced by Tatung Science & Technology Inc., also packs away much more storage capacity than most. Users of the 40-MHz Compstation 40 can choose from 207-, 340-, or 535-Mbyte internal hard-disk storage. The station also accommodates dual drives so the Compstation can handle as much as 1 gigabyte, suitable for multi-user environments with applications including large databases and high-end graphics. Price of the workstation starts at $8990.

Coming in below $7000 was CompuAdd Computer Corp. For $6995, CompuAdd introduced a 40-MHz "third-generation" Sparc workstation. The model SS2 operates at 28.5 million instructions per second (MIPS), and is available in stand-alone and diskless network versions. Up to 64M bytes can be installed on the mother board, and a variety of SBus expansion cards are available.

AT THE LOW-PRICE END. RISC machines also got high marks at Hewlett-Packard Co. This January the company introduced workstations it claimed had benchmark performance exceeding that of the highest-performing workstations offered by Sun and others. Yet these machines were down at the low-price end of the workstations business.

The machines are part of the HP Apollo

Representative sample of newest workstations *(continued)*

Company	Model	Unit cost, US $	CPU (clock speed)	Operating system	Memory[a] Main, Mbyte	Memory[a] Total cache, Kbyte	Features and comments
OEM Engines Inc.	28/40	$13 995	Sparc (40 MHz)	Unix, Sun/OS 4.1.1	64–128	64	Includes monitor, 400-Mbyte hard drive, 3.5-inch floppy, graphics accelerator; 100 percent binary compatible with Sun Sparcstation 2; available as upgrade to earlier Sun Sparc models
Opus Systems	PM 5124	$7205	Sparc (40 MHz)	Sun/OS, Solaris 1.0	16	64	Frame buffer supports 1024 X 768-pixel standard PC monitors
Polywell Computers Inc.	Poly 486-50V	$5500	80486 (50 MHz)	DOS, Unix, OS/2	16–32	256	Includes video accelerator card; 20-inch 1280 X 1024-pixel monitor; 200-Mbyte hard disk, with option to 2.5 Gbytes and 32M-byte RAM
RDI Computer Corp.	Britelite IPX Color	$14 995	Sun IPX (40 MHz)	Sun/OS 4.1.1	16–64	64	Laptop; active-matrix liquid-crystal display; 240-Mbyte hard drive; SBus, SCSI, Ethernet, and serial ports; 1152 X 900-pixel monochrome display available
Silicon Graphics Inc.	Iris Indigo	$7995	R3000A (33 MHz)	Irix	8–96	32 (data and instruction)	Fast 2-D and 3-0 graphics; digital-audio tape quality audio; virtual 24-bit color, 133-Mb/s GI032 bus transfer rate, 30 MIPS, 4.2 MFlops, 26 Specmarks
Solbourne Computer Inc.	S4000DX	$4995	Sparc (proprietary)	Solbourne OS/MP (derived from Sun/OS)	8 or 128	8–256	Color monitor; high-performance SBus with 3 expansion slots; X-Window system compatible with Solbourne, Sun-4, and Sparcstation workstations, servers
Sun Microsystems Inc.	Sparcstation IPX	$11 995	Sparc (40 MHz)	Sun/OS	16–64	64	Fast, 2-D/3-D wireframe graphics; 8-bit color, 480 000 2-D and 310 000 3-0 vectors/s, 24.4 Specmarks
Tandy Corp.	Tandy 2825 SX	$1999	80486SX (25 MHz)	DOS, OS/2, Unix/Xenix	4	8	Intel 80487SX (optional); supports X.25, OSI and SNA protocols
Tangent Computer Inc.	Tangent 433E	$4995	80486 (33 MHz)	DOS, Unix, OS/2	8–64	128–256	4M-byte RAM on caching controller; 200-Mbyte hard disk; runs Windows five times faster than other VGA cards
Tatung Science & Technology Inc.	COMPstation 40	$8990	Sparc (40 MHz)	Sun/OS 4.1.2, Solaris 1.0.1	8–64	64	Includes high-resolution 19-inch color monitor, graphics accelerator card, Motif GUI, 3 SBus slots; upgradable to 128 Mbytes with add-on cards
TwinHead Corp.	Twinstation	$9995	Sparc (40 MHz)	Sun/OS 4.1.2	16–128	64	17-inch color monitor; Sun GX graphics
Visual Information Technologies Inc.	VITec-60/TC	$39 100	Custom RISC	Sun/OS 4.1 and 4.1.1, Unix, Solaris 1.0.1	8–264		3-board set, 6U form factor; supports Open Look and Motif GUIs, X-Windows; 300 million operations/s; stereo operations
Wyse Technology Inc.	Oecision 486/33	$3299	80486 (33 MHz)	OOS, Unix, OS/2	2–32	128	Secondary 128K-byte cache; socket for coprocessor; 7 ISA expansion slots and 4 half-height mass storage shelves
Zenith Oata Systems Corp.	Z-486/33E, Model 200	$6599	80486 (33 MHz)	DOS, Unix	4–64	8	200-Mbyte drive; 1024 X 768-pixel display; Texas Instruments 34010 TIGA graphics processor; EISA bus; 64-bit memory bus; VGA support

a M here means 1024^2, K means 1024.

CAD/CAM/CAE = computer-aided design/manufacturing/engineering; CPU = central processing unit; EISA = extended industry standard architecture; FDDI = fiber distributed data interface; Flops = floating-point operations per second; ISDN = integrated-services digital network; MIPS = million instructions per second; RISC = reduced-instruction-set computer; SNA = systems network architecture.

X terminal: a workstation alternative

From a user's perspective, a workstation is ultimately a set of input and output devices, such as a keyboard, mouse, and video monitor, that open up access to computational capability. If this input/output set reacts quickly and responds clearly and reliably to the user's requests, then he or she does not really care where data is stored or processed. Take away a workstation's ability to store and process data locally and—*voilà!*—you have an X terminal, which can fulfill many users' needs while reducing the overall cost of supplying engineering "seats."

The X Window System standard was developed at Massachusetts Institute of Technology and is administered by the X Consortium. Today's terminals adhere to the 11th version, now in the fourth revision (X11.4). X terminal hardware consists of a display with graphics driver, a communication link, and input devices, such as a keyboard and mouse or trackball. It does not need any general-purpose CPU or memory of its own; it relies symbiotically upon the resources of a host computing environment to perform the tasks its user requires. It can be attached to a local-area network in the same way as a file server or printer, or to a workstation directly with, say, an RS-232C link, like an external modem. The software for host-terminal communication resides partly in the host and partly in the terminal.

X terminals range in price from less than US $1000 to over $9000 (depending primarily on graphics and communication capabilities), which can be much less than the cost of a new workstation. In configuring systems with X terminals, system administrators must consider what applications will be run and how much of a burden those applications, plus communication overhead, will place on the host environment. A listing of X terminal suppliers is provided in the index [p. 60].

A discussion of X terminal basics appears in the article "Anatomy of an X terminal" by A. Socarras, R. Cooper, and W. Stonecypher [*IEEE Spectrum*, March 1991, pp. 52–55]. For a detailed understanding of the X Window System, see the nine-volume series, *The Definitive Guide to the X Window System*, now in its second edition (O'Reilly & Associates Inc., Sebastopol, Calif., 1990).

—*Richard Comerford*

9000 Series 700, introduced about a year before, and employ the company's Precision Architecture RISC (PA-RISC) CPU. Also in January, HP extended its graphics offerings and announced a new family of workstation servers—the CRX-24 and CRX-24Z color graphics systems and Series 700 servers.

HP's performance leader for entry-level workstations is the model 705 desktop, which for $4990 delivers 34 Specmarks and 35 MIPS. But HP's fastest workstation in the under-$10 000 price range is the model 710. It delivers nearly 50 Specmarks and 57 MIPS.

PORTABLE POWER. Can a portable computer qualify as a workstation? Yes, say some manufacturers. It qualifies when the machine is powerful enough to be taken on the road to perform the types of engineering tasks usually handled on office workstations.

This is the claim made by Dolch Computer Systems for its P.A.C. 486-50E. The model number spells out the microprocessor in the machine's guts—Intel's 50-MHz version of its 80486. The 21.5-MIPS machine is an addition to earlier Dolch 80386 models and an 80486 model with a 33-MHz microprocessor.

The single-unit price of the P.A.C. 486-50E is $9000, including 32-bit EISA architecture, a 120-Mbyte drive, a 1.44-Mbyte floppy, a VGA display, and four expansion slots. The latter are the rationale for the initials in the model number, which stand for portable add-in computer. A gas-plasma display offering 16 shades of gray is standard, and a thin-film-transistor active matrix display is a color option.

[The past year also saw great user interest in notebook computers that are smaller than portables yet pack plenty of power. Apple Computer, IBM, and the IBM-compatible makers were busy introducing models. Indeed, the notebook segment of the PC marketplace has been growing the fastest.]

GRAPHICS. Taking aim at the display of 2- and 3-D graphics are new systems like those from Intergraph Corp. and Silicon Graphics Inc. Intergraph's three-model series 2400 desktop workstations rely on the Clipper C400 RISC microprocessor, a newer version of the company's proprietary design.

With 33 Specmarks and 10 MFlops performance, the three workstations in the series operate with 8-bit, double-buffered raster memory planes and vector drawing rates of 500 000 2-D and 300 000 3-D vectors per second. They are available with single or dual 19-inch color monitors. Intergraph's mid-range model IP2430 sells for $18 500.

Silicon Graphics unveiled the first model of its Iris Indigo family of desktop graphics workstations in July 1991, then followed with three more increasingly powerful members in January. Built around the MIPS R3000A RISC processor, the family offers 3-D graphics, digital-audio-tape quality sound, and is ACE-compatible.

According to Silicon Graphics, the systems' graphics performance equals that found in the company's $50 000-and-up Iris Power Series GTX computers, which the new systems replace. But now the base price of the four members of the family ranges from $7995 for Iris Indigo to $27 000 for the top-of-the-line Iris Indigo Elan.

Also in January, Silicon Graphics introduced seven single-user deskside workstations and servers, the Iris Crimson family. These are the first units built around the MIPS R4000 64-bit processor—the 50-MHz MIPS R4000SC delivering 70 Specmarks. The systems start at $27 900. ◆

Introducing Po
For Project

The #1 Rated Project Manager Now Available For Windows.

Power changes people.

Especially project managers.

They work smarter and faster with new CA-SuperProject™ For Windows. It's always been the world's most advanced, efficient and reliable project management software.

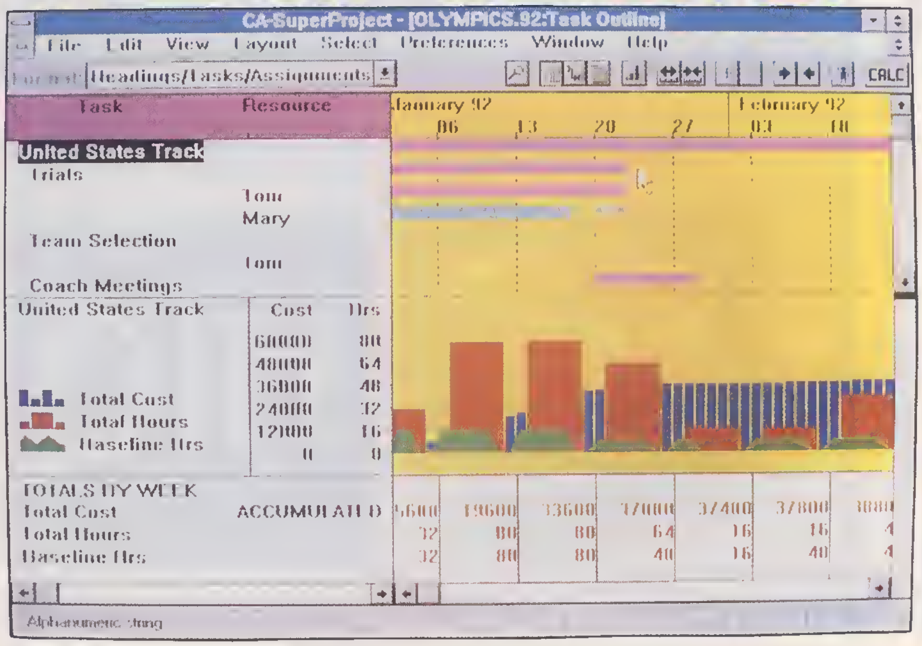
And now that it's Windows compatible, it's also the easiest to use.

Total power is yours with a few mouse clicks. Graphically create and edit projects. Specify resources, task types and durations. Define integrated sub-projects. Build top-down hierarchies and task-dependency relations. Link multiple projects together for cross-project leveling.

Perform extensive "what-if" analysis, revising schedules as projects progress.

You can bet your career on its advanced algorithms, which calculate the most efficient project schedules in the industry.

MICROSOFT® WINDOWS™



New CA-SuperProject For Windows gives you all the power you'll need for any project with tools for sophisticated planning, comprehensive resource management and powerful tracking and controlling.

Create, edit, view– total power over any project is yours with just a few mouse clicks.

...ower Windows Managers.

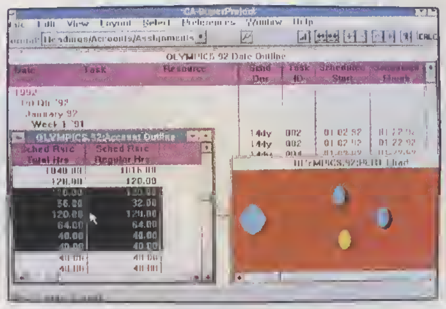
A recent study of the five leading project managers proved it. Each was assigned the same project, but the completion dates varied by as much as five months.

CA-SuperProject For Windows finished first in 214 working days—leaving Microsoft Project, Timeline 4.0, Project Workbench and Project Scheduler in the dust.

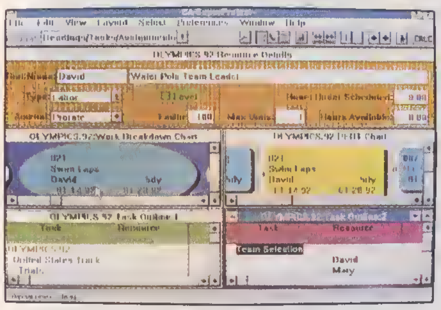
Vibrant, state-of-the-art graphics and detailed reporting tools help bring your projects to life.

You can choose from

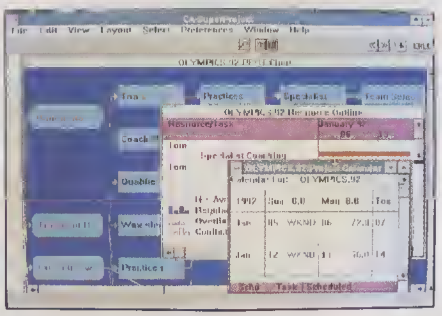
Start by specifying resources, task types and task durations—all in a matter of seconds.



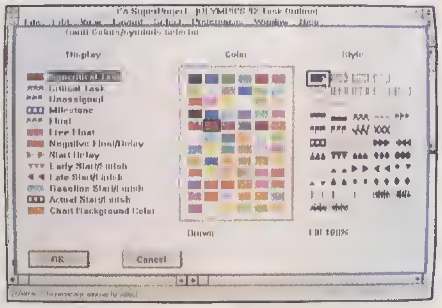
Perform extensive "what-if" analysis, revising schedules as your projects progress.



Show multiple views of the same project or different projects simultaneously.



Report the status of your project with detailed Gantt, PERT, WBS and Cost/Resource charts.



Bring projects to life with a full array of WYSIWYG on-screen interactive graphics, colors, fonts, symbols and shade patterns.

WYSIWYG fonts, symbols, colors and shade patterns to highlight your Gantt, PERT, WBS and Cost/Resource charts.

For your free Demo Disk, call 1-800-CALL CAI.

Call today.

And find out what our power windows can do for you.

COMPUTER® ASSOCIATES
Software superior by design.

CA-SuperProject® For Windows

Circle No. 203

Add-ons add versatility

The desire for enhanced graphics is bringing new and improved processing, storage, manipulation, and display systems to market

The stagnant U.S. economy in the last year has not put a damper on the introduction of add-ons for workstations. In fact, because they can offer improved performance without having to replace an entire workstation, these products seem to be faring quite well in what has been a difficult market. However, the real driving force behind this activity is visualization; the ability to create a dynamic, interactive view of a computer-generated environment or scientific solution is quickly becoming a "must have" feature.

As a result, several important product developments have sprung up since *IEEE Spectrum*'s last workstation report a year ago. Among them are: boards that dramatically increase drawing speed, memory systems that provide vast amounts of storage inexpensively and reliably, and input devices and monitors with increased resolution [see table].

Richard Comerford Senior Editor

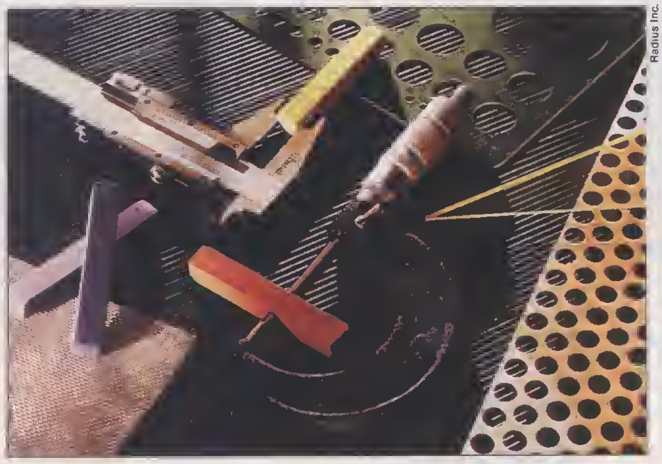
FASTER, TOGETHER. Upgrading a workstation's central processing unit (CPU) is becoming a common option. In addition to new performance-boosting chip sets that are architecturally compatible with the CPUs and the coprocessors they replace, the latest offerings include boards that introduce new architectures to existing systems.

For example, Avalon Computer Systems Inc.'s Vaccelerator AP/30 CPU board puts a Motorola Inc. MC88100 reduced-instruction-set computer (RISC) processor alongside the regular CPU of a PDP-11 minicomputer—in effect turning it into a workstation—while RasterOps Corp.'s ImagePro puts an LSI Logic Corp. 33000 RISC chip next to the Macintosh's Motorola CPU.

If adding a single processor provides less than the necessary power boost, then perhaps multiprocessing is the answer. Several boards are built around Intel Corp.'s i860 family of processors: Alacron Inc.'s AL860 XP AT and Microway Inc.'s Number Smasher-860 for PCs, as well as Mercury Computer Systems Inc.'s MC860VS and SKY Computers Inc.'s SKYbolt-mp for Sun Microsystems Inc.'s workstations. These systems allow from two to four processors to work concurrently on problems, providing performance from 80 to 320 millions of floating-point operations per second (MFlops).

In the table, the largest number of processors in a single system is 256; the SuperSetPlus from Computer System Architects employs 16, 64, or 256 transputers (T425 or T800) from the Inmos Division of SGS-Thomson NV. The system can be partitioned so that 16 users can work simultaneously, and Macintosh, PC, and Sun workstations can access the system either directly or over a local-area network.

For logic and fault simulation, the market leader in accelerators remains Zycad Corp., with its XP family. These systems can simulate from 64K to 1M gates for fault simula-


Radius Inc.


Sony Corp.


GTCO Corp.


Conner Peripherals Inc.

Recent products underscoring visualization demands include (clockwise, from upper left) Radius Inc.'s 20-inch display, which switches resolution on the fly; Sony Corp.'s optical drive, both write-once and erasable media; Conner Peripherals Inc.'s 510-Mbyte Chinook drives, which handle 140 I/Os per second; and GTCO Corp.'s space-saving Roll-Up digitizer.

0018-9235/92/$3.00©1992 IEEE

Representative sample of add-on boards and peripherals for workstations

Company	Product	Year first available	Unit cost, US $	Key features and comments
Hardware accelerators and coprocessors				
Alacron Inc.	AL860 AT/VME	1990	$3500+	50–200 MFlops; modular I/O daughter boards
Analogic Corp.	MSP-6C30	1991	$8900	High-speed floating-point VME array processor; dual TMS 320C30 processors; signal-processing and imaging libraries
Aox Inc.	AOX Micro-master 486	1990	$3860–$4990	Bus-master processor upgrade board for IBM PS/2; supports up to 16M bytes of 32-bit memory on-board
Avalon Computer Systems Inc.	Vaccelerator AP/30 for PDP-11	1991	$4900–$7900	RISC CPU with 18 or 36 VAX MIPS support for RSX-11M-Plus, RT-11, TSX; larger address space (up to 1G byte) eliminates need for overlays; provides migration path to VAX/VMS for Fortran or C applications
Computer System Architects	SuperSet Plus	1991	$20 000	T805 32-bit transputer array for simultaneous use by up to 16 on PC, Mac, or Sun workstations; maintained with no operating system overhead; expandable from 16 to 64 or 256 processors; processor modules available separately
CSPI	Supercard SC-2X1	1991	$9000–$14 000	i860-based vector processor; 160 MFlops on a 6U VME board; C, Fortran compilers, signal- and image-processing libraries optional
Datel Inc.	PC-30	1992	$3995	Digital signal; processing board with analog-to-digital (A/D) converter front end; menu-driven data analysis software available
Inmos	IMS B404-15 (with B008-1 PC)	1990	$3203+	T805-based 32-bit transputer module; includes scalable software, floating-point, 2M-byte memory; PC (ISA) mother board has 10 module slots; mother boards for Micro Channel (MCA) and VME also available
Mercury Computer Systems Inc.	MC860VS	1991	$20 000–$70 000	80 MFlops to 2.5 GFlops in 1 to 8 VME slots; up to 2G bytes of memory; hardware and software support for data acquisition and real-time processing; Sun, Silicon Graphics, and chassis systems
Microway Inc.	Number Smasher-860	1990	$5000–$6000	Very high-speed numeric coprocessor board; i860s can be run in parallel; 80-MFlops throughput, EISA and ISA (PC) bus-compatible; includes either NDP Fortran, C/C++, or Pascal i860 compiler
Myriad Solutions Ltd.	DASH!860	1991	$3995–$7995	i860 accelerator for PC; integrates DOS development environment with Windows support
National Instruments Corp.	AT-DSP2200	1991	$2495	DSP board with dynamic signal acquisition analog I/O; gives PCs a high-speed engine for scientific/engineering calculations
Performance Semiconductor Corp.	PaceRunner/3400	N.A.	N.A.	Double-height 6U VME 25- or 33-MHz RISC board with 64K-byte instruction and 64K-byte data caches, 4M-byte dynamic RAM (expandable to 16M bytes), two RS-232C ports, and SCSI and Ethernet controllers
Radius Inc.	Radius Rocket	1991	$1999	Increases speed of original Mac II up to six times; 68040 processor with integrated math coprocessor; for CAD, 3-D rendering, and scientific analysis
RasterOps Corp.	ImagePro	1992	$999	First RISC-based expansion adapter; allows compute-intensive tasks; can handle large imaging applications and perform accelerated compression/decompression in JPEG or QuickTime format
SKY Computers Inc.	SKYbolt-mp	1991	$12 990	Up to 4 i860s with 16M bytes each for 320 MFlops; single 9U VME slot with VSB-(standard bus) VME-system bus and auxiliary port I/O option; compatible with Sun-3 and -4 workstations; full C and Fortran 77 vectorizing compilers and tools; client support for XLIB, a standard graphical user interface
Zycad Corp.	XP Family	1990	$47 500	Transparent interfaces to major CAE simulation environments; accelerates concurrent fault simulation; has become *de facto* standard for hardware acceleration
Interface and adapter boards				
Local-area networks (LANs)				
Antares Microsystems Inc.	ConServer 20-050-005	1991	$845	Thin Ethernet controller and SCSI host adapter SBus board for Sun workstations and compatibles; single-width to save slots; builds desktop servers
Evergreen Systems Inc.	CAPcard	1992	$1495–$1995	AT-bus communications/applications processor card for LAN; contains 25-MHz 386SX, 2M- to 16M-byte RAM, VGA video, 2 serial and 1 parallel port; 2 disk interfaces, Ethernet with AUI and RF-45 connectors, CAPlink interface, MS DOS 5.0, and pcANYWHERE
SMC (Standard Microsystems Corp.)	EtherCard PLUS Elite 16 Combo	1991	$349	16-bit Ethernet board for AT bus; AUI, BNC, and RF-45 connectors; autosensing of RJ-45 or BNC port based on cable connection, AUI software-selectable; installs with two jumper settings or EZsetup program; broad driver support
Interface and expander boards				
Analyx Systems Inc.	ADDA-1418	1992	$2495	Single-slot data acquisition system for SBus; isolated; sixteen 14-bit A/D and four 18-bit D/A channels; sample rate programmable from 6 μs to 1.536 ms; 128K-byte dual-ported RAM; includes Unix driver and direct-access user program
Antares Microsystems Inc.	20-050-0015 SBus 8-channel serial controller	1992	$1495	Bidirectional FIFOs minimize CPU overhead; full modem controls on every port; desktop, wall, and rackmounting options; up to 24 channels, 384 kb/s
Atlanta Signal Processors Inc.	Multi-rate Digital Audio System	1991	$11 950	Allows use of digital-audio-tape decks and compact-disc players with Sun workstations; sampling rates of 8, 10, 16, 20, 32, 44.1, or 48 kHz software selectable; single 6U-4HP VME slot

Representative sample of add-on boards and peripherals for workstations *(continued)*

Company	Product	Year first available	Unit cost US $	Key features and comments
Interface expander and boards				
Barr Systems Inc.	RS232/V.35 Adapter	1983	$1790	Synchronous adapter for SNA and BSC; speeds to 384 kb/s; supports RJE and 3270 access
Data Translation Inc.	DT3831	1991	$2995–$3695	Data acquisition board with embedded anti-aliasing filters, real-time error prevention circuitry
Helios Systems	HeliosPORT and SDM 4/1 (4 ports)	1991	$615	1-to-4-port expander; "Mini Brick" design mounts directly on back of workstation and plugs into SBus card; 8-port version also available
IOtech Inc.	SB488	1990	$995	SBus-compatible IEEE-488 controller; single board controls up to 14 IEEE-488-compatible devices; direct memory access at 1 Mbyte/s; includes driver software for Sun/DS 4.0.3c
Keithley Metrabyte	KPC-488.2AT	1992	$495	IEEE-488 controller for PC AT; up to 1.5-Mbyte/s data transfer rate; built-in software bus analyzer
National Instruments Corp.	GPIB-SPRC-B	1990	$995	Single-slot plug-in SBus board; NAT4882 and Turbo488 ASICs for complete IEEE-488.2 compatibility; data transfer rates of over 1 Mbyte/s for both reads and writes
Graphics adapters				
ATI Technologies Inc.	Graphics ULTRA	1991	$599–$699	Combines Super VGA- and 8514/A-compatible coprocessing graphics on a single board; supports up to 1280 × 1024 interlaced in 16 colors and up to 1024 × 768 at 76-Hz refresh rate; provides graphics acceleration for Windows and DS/2
Barco Chromatics Inc.	CX3500	1992	$11 950	Up to 2 million vectors/s; 40-MHz 68030 I/O processor, one to three 40-MHz M96002 display list processors; two display heads; resolution to 2560 × 2048; up to 64M bytes with 8 planes and 8 overlays; compatible with VME, Sbus, MCA, and Turbo Channel
Micron Technology Inc.	MacroColor II (MGXC12)	1991	$569	For Macintosh II family; 24 b/pixel, up to 16.7 million colors; also 1-, 2-, 4-, and 8-bit modes; works with multiple-monitor environments; software includes Virtual Video for desktop expansion beyond 640 × 480 pixels and MacroPaint 8/24
Myriad Solutions Ltd.	ShadeMASTER	1991	$1500–$2500	Graphics adapter for DASH!860 accelerator card; software selectable resolutions of 1280 × 1024 × 8 or 800 × 600 × 24 bits; drawing rate to 100 million pixels/s
Radius Inc.	Precision Color 24X	1992	$1999	Displays 24-bit color; includes on-board Quickdraw acceleration; drives various displays at multiple resolutions
RasterOps Corp.	24XLi	1991	$2499	Custom ASICs accelerate display up to 600%; supports many 13- to 19-inch monitors; provides photorealistic capabilities and fast drawing speeds
RGB Spectrum	RGB/View	1989	$7995–$9975	Video windowing system compatible with all workstations; 9U VME or stand-alone unit available for almost all displays; real-time video or second computer signals, or forward-looking infrared (FLIR) in a window on the workstation
Univision Technologies Inc.	UDC-8000-TI	1992	$3495	IBM RISC/6000 Micro Channel graphics controller based on TMS34020 (floating-point TMS34082 optional); 40 MFlops and 200 000 vectors/s; resolution to 1600 × 1280 × 8 bits, single or double buffered; optional VSB and digital camera interfaces
Storage and backup systems				
Memory boards				
Dataram Corp.	DATARAM DR9700	1991	$2000–$4300	Fully compatible (hardware/software) with HP Series 9000 Model 700 workstations; lifetime warranty
Helios Systems	DN 5500	1991	$2320	100% compatible with HP Apollo systems; 16M bytes; lifetime warranty; 30-day money-back guarantee
Parity Systems Inc.	PS4490	1991	$3998	32M-byte board for Sun Sparcstation 470, Sparcserver 470/490; uses upgradable/replaceable single in-line memory modules; 128M-byte version; lifetime warranty
Tecmar Inc.	MicroRAM	1990	$380–$1180	1M–32M bytes of Micro Channel memory; automatic installation is operating system independent
Western Automation Laboratories Inc.	Acumen 5000 4MB	1990	$2500	Low-cost 4M-byte memory alternative, 100% compatible with NCR Tower series
Winchester Technology	Memory Board	1992	$50–$150	1M- to 4M-byte memory boards for Sun, PC, HP, DEC, and Silicon Graphics
Magnetic-disk drives				
Conner Peripherals Inc.	Chinook Series CP	1992	N.A.	For high-end workstations, file servers, and multi-user systems; 510 Mbytes; dual-actuator design; 3-ms seek time; up to 140 I/Ds per second
Iomega Corp.	Bernoulli 90MB Workstation (Dual)	1991	$2599	Dual 90-Mbyte, 5.25-inch external drive for workstations with removable disk drives; 100M-byte on-line expansion; support for Unix, Xenix, Sun OS, and AIX
Mega Drive Systems Inc.	Mercury	1992	$389+	Removable hard drives for security, networking effectiveness; up to 1-Gbyte storage per drive; can be daisy-chained for up to 7-Gbyte storage
Micropolis Corp.	Raidion	1991	$9000–$35 000	Modular, high-performance disk array; can be configured as a two-drive mirrored system with 1.7 Gbytes; adding 1 to 24 more modules converts it to a RAID/level 5 fault-tolerant subsystem with up to 47 Gbytes

Company	Product	Year first available	Unit cost, US $	Key features and comments
Sysgen Inc.	Mobile Disk	1991	$550–$895	Portable hard drive for IBM-compatible PC, portable or laptop; 40-, 80-, or 120-Mbyte versions; snaps onto parallel printer port for no-tool installation
Winchester Technology	Magnetic Disk Drive	1992	$3500	For Sun, DEC, HP, IBM PCs and RISC/6000; 700 Mbyte capacity
CD ROMs				
Sony Corp. of America	CDU-7211	1991	$950	Half-height external drive; supports SCSI I and II, Microsoft Multimedia PC standards; interface kits available for IBM PS/2, PC, XT, AT, and compatibles
Erasable optical drives				
Insite Peripherals Inc.	1325VM Floptical Disk Drive	1991	$295 (OEM qty)	Uses magnetic and optical technology to store 21 Mbytes on removable 3.5-inch diskette; compatible with 720-kbyte and 1.44-Mbyte magnetic disks
Iomega Corp.	Laser Safe	1991	$4999	600-Mbyte rewritable magneto-optical subsystem for workstations; uses removable ISO-compliant disks; 256K-byte, dual-ported intelligent cache; external voltage select for use overseas
Sony Corp. of America	SMO-E501	1990	$4650 (list)	Stores 650 Mbytes on 5.25-inch double-sided ISO/ANSI media; thermomagnetic recording; embedded SCSI controller; 70-ms average seek time; 7.4-Mb/s sustained and 1.2-Mbyte/s burst data transfer rates; 250 000 load/unload cycles
Tecmar Inc.	LaserVault 650MB	1990	$5995	Lets the same cartridge work with different computers running different operating systems; LaserBack software lets all or part of an optical cartridge serve as a virtual tape for archival storage; for DOS, Mac, Novell, OS/2, LAN Manager, LANtastic, Unix, and Sun
Multifunction optical-disc drives				
Literal Corp.	525MF	1991	$4995	Stores up to 675 Mbytes on 5.25-inch WORM or erasable ISO-standard media
Sony Corp. of America	SMO-E511	1991	$4895	Stores up to 650 Mbytes on 5.25-inch WORM or erasable optical discs; compliant with ANSI/ISO standards
Write-once, read-many (WORM) drives				
Literal Corp.	525GB+	1991	$3999	Very high capacity; stores up to 1.280 Gbytes on 5.25-inch disk; ANSI and ISO standards media option
Sony Corp. of America	WDA-610	1989	$180 000	Autochanger (jukebox) accommodates up to 50 disks for 328 Gbytes of storage (12-inch, 6.55-Gbyte); up to 7 autochangers can be daisy-chained to store 2.3 Tbytes
Magnetic tape systems				
Alloy Computer Products Inc.	Retriever 2200 AOY21-01	1990	$5145(AT) $5545 (MCA)	Includes 16-bit SCSI interface, tape-backup software, and utility software; backs up workstation drives as well as server drives
Irwin Distribution	AccuTrak Plus	1991	$249	Low-priced mini-cartridge tape-backup system; models for AT bus or Micro Channel as well as external versions; software data compression (range from 40 to 250 Mbytes); Windows backup software optional
Parity Systems Inc.	PS5900 Tower Subsystem	1991	$15 000–$70 000	4.8–20 Gbytes of disk storage; 4–12 SCSI devices packaged in drawers that are easily removed for upgrade/replacement
Spectra Logic	Spectra Tape 850	1991	$8930	Uses 8mm tape; plug-on backup solution using existing Pertec or STK controllers
Tecmar inc.	DataVault 2GB	1989	$4695–$4995	User-selectable software data compression doubles tape capacity to 4 Gbytes; up to 10.9-Mbyte/min backup-and-restore speed; software solutions for DOS, Mac, Novell, OS/2, LAN manager, LANtastic, Unix, and Sun
Wangtek Inc.	51000SS	1992	$2995	Sun/Sparc compatible; 1G-byte capacity; backup speed up to 12 Mbytes/min; includes tape drive, enclosure with power supply, cabling, and Legato Networker software
Input devices				
Mice				
KYE International Corp.	CLIX ES Mouse by Genius	1992	$49	Ergonomic, streamlined design; opto-mechanical right- and left-hand mouse; adjustable resolution 350 to 4200 dots/inch; comes with or without Paint
Mouse Systems Corp.	SPARKY 903571-002	1992	$100	Three-button opto-mechanical unit; 100% compatible with Sun Sparcstation; ergonomically shaped; 250 dots/inch
Track balls and light pens				
FTG Data Systems	FT-256	1990	$388	Easy-to-use, direct-input light pen for AT-compatible or PS/2 computers; includes interface board, Windows driver, and mouse-emulation software; gives desktop PC entry to pen-computing software
ITAC Systems Inc.	Mouse-trak	1988	$199	Track ball for DEC, HP-Apollo, and Sun workstations; up to 3 keys user-definable; cursor-speed select button; wrist pad; PC, Mac versions
Kensington Microware Ltd.	Expert Mouse	1989	$150	Track ball's acceleration algorithms provide smooth cursor control; Expert Mouse is PC version of Turbo Mouse, which has won more awards than any other Mac input device
KYE International Corp.	GeniTrac GK-T320	1991	$120	Microsoft- and Mouse Systems-compatible track ball; 350 to 1050 dots/inch
MicroSpeed Inc.	MC-TRAC (PD-350)	1990	$119	Track ball for Mac; ergonomic design; control-panel software

Representative sample of add-on boards and peripherals for workstations *(continued)*

Company	Product	Year first available	Unit cost, US $	Key features and comments
Digitizer tablets				
Altek Corp.	DATATAB Digitizers	1977	$895+	Accuracies of ±0.003, ±0.005, and ±0.010 inch in sizes ranging from 12 × 12 to 60 × 120 inches; available nonbacklit or backlit
GTCO Corp.	Roll-Up Digitizer	1991	$1895	Rolls up for easy storage; portable; available in 30 × 36- and 36 × 48-inch sizes
Kurta Corp.	Kurta IS/One	1987	$645	For CAD and graphics; executes batches of keystrokes with one touch
KYE International Corp.	Genitizer GT-1212B/+	1991	$429–$479	9 × 6 to 12 × 18 inches; AutoCad/CasCad II template; adjustable 4-button cursor and 3-button stylus; 3-year warranty
Numonics Corp.	GridMaster	1985	$469 up	Flexibility; no power supply required
Science Accessories Corp.	GP-9 Sonic Digitizer	1990	$2195	No special digitizer surface; programmable output format; small footprint; active area 900 × 1200 mm; resolution selectable to 0.100 mm; under 5 kg
Scriptel Corp.	RDT-2436 Transparent Digitizer	1988	$4195	Surface-mounting technology; 8-digit display communicates all user set-up commands; designed for backlit and rear-projection uses in medical, dental, radiology, mapping, estimation, and animation markets
Summagraphics Corp.	SummaSketch II Plus	1991	$599	2000 lines/inch; accuracy, 0.010 inch; latest generation of the industry's best-sellling tablet
Wacom Technology Corp.	Super Digitizer SD-420E	1989	$995	Stylus is cordless, batteryless, and pressure-sensitive; accurate to ±0.15 mm; available with electrostatic surface to hold papers securely to surface without taping
Output systems				
High-resolution monitors				
Amdek	AM/817	1991	$1299	Intelligent, 17-inch high-resolution non-interlaced color screen
Radius Inc.	Precision Color Display/20	1991	$3299	20-inch multifrequency display for Mac and PC environments; "on the fly" resolution switching from 640 × 480 to 1152 × 882 on Mac, 320 × 200 to 1024 × 768 on PC
RasterOps Corp.	Sweet 16	1992	$2495	High resolution/definition; flicker-free video output
Sony Corp. of America	GDM-1936	1990	$3995	For high-end CAD/CAM applications; 20-inch Trinitron Multiscan color graphics display with resolution to 1280 × 1024; provides 9 built-in display standards
Graphics printers and pen plotters				
Houston Instrument	DMP-160 series	1991	$4595–$5995	Pen plotter; HPGL-2; ADI driver, Windows driver available; 512K-byte memory
RasterOps Corp.	CorrectPrint 300	1992	$10 999	Four-color dye sublimation photorealistic graphics printer; RISC-based controller with JPEG decompression capabilities; PostScript-compatible
Tektronix Inc.	Phaser III PXi	1991	$9995	Prints in color on plain paper up to 12 × 18 inches; 300 dots/inch
Scan converters				
Folsom Research Inc.	Video/Scan 9100	1991	$9950	Real-time scan converter and frame grabber for Sun, HP, IBM, and DEC workstations; SCSI interface for digital image transfers
RGB Spectrum	RGB/Videolink 1600	1991	$19 495	Stand-alone unit that synchronizes automatically to all workstation signals; pan, scroll, and zoom; composite-NTSC, S-Video, and RGB outputs, 31.5-kHz output for projection

ASIC = application-specific IC; CAO/CAE/CAM = computer-aided design/engineering/manufacturing; CPU = central processing unit; OSP = digital signal-processing; FIFO = first-in, first-out (memory); Flops = floating-point operations per second; LAN = local-area network; RISC = reduced-instruction-set computer; WORM = write once, read many (memory).

tion (256K to 4M for logic) and provide algorithms to simulate up to 16 faults concurrently per simulation pass.

BETTER VIEW, MORE ROOM. A recurrent problem for most users is trying to pack everything they want into their systems—including large amounts of RAM, special graphics accelerators, digital signal-processing boards, digital and analog I/O cards, and the small computer systems interface (SCSI) and Ethernet interface.

To open up systems, board manufacturers are making their products more compact and capable. For example, Antares Microsystems Inc.'s ConServer thin Ethernet controller board is single- (rather than double-) width, which frees up a slot on a Sun system's SBus.

Likewise, Helios Systems' HeliosPORT uses what is called a Mini Brick design to increase the number of devices that can be hooked to a workstation. It mounts on the back of a workstation, connecting an Sbus SCSI board to as many as eight ports.

Increasing demand for high-resolution graphics for visualization is pushing suppliers to rev up the performance of graphics adapters. RasterOps' 8/24XLi accelerates drawing speed by up to 600 percent, while Radius Inc.'s Precision Color 24, in addition to providing a 24-bit color palette for Macintoshes, accelerates Quickdraw functions. The company's recent pact with Apple Computer Corp. to license operating system technology should result in even faster display capability.

Visualization, with its vast data requirements, is also creating a demand for an affordable data link that is faster than SCSI or Ethernet. Enter the fiber channel. In late February, IBM Corp. and Hewlett-Packard Co. announced that they would jointly develop, manufacture, and market a fiber channel card for workstation OEMs—one that complies with the new American National Standards Institute's Fiber Channel standard. The standard encompasses a wide variety of protocols—such as SCSI, Hippi, and FDDI—and physical media.

The new card will be based on the one IBM is currently offering for its AS/400 minicomputers and RISC System/6000 workstations. Initially, cards will provide a raw data rate of 266 Mb/s (versus Ethernet's 10 Mb/s) while retaining compatibility with existing data transfer protocols. Most importantly, the price of these cards—hundreds rather than thousands of dollars—will make them affordable even for low-end systems.

GIGABYTES. Demand for improved graphics capabilities is one of the main reasons why users are also upgrading storage systems. Whereas 40 Mbytes was considered more than adequate for many applications three years ago, minimum system requirements of 100–500 Mbytes are the norm today, with demand for 1-Gbyte storage pushing into the mainstream. Thus one can now find high-capacity disk systems at highly competitive

prices—as little as US $2 to $3 per Mbyte.

The leading edge in magnetic-drive storage is a new technology called redundant array of inexpensive disks (RAID). There are five levels of RAID, numbered in increasing order depending on a combination of access speed and data reliability.

Micropolis Corp. is now offering a RAID 5 system, the highest level. In such a system, data can be transferred in parallel to different drives so that the overall throughput is very high, as much as 20 Mbytes per second (hence the need for a transfer path like fiber channel).

For reliability, error-correcting codes (ECCs) are dispersed throughout the system so that the likelihood of a magnetic-disk defect corrupting data is very low; in the case of a one-disk failure, data can be recovered from other disks through ECCs.

At present, RAID systems rely upon well-established magnetic-disk technology. But that technology is quickly being challenged by optical storage. In the past year, a new form of optical-media system has pumped up the market: multifunction optical drives.

These new systems work with both write-once, read-many (WORM) and erasable optical media, letting the user make archival as well as temporary copies of large amounts of data (typically, optical media hold over 600 Mbytes). Two such drives, from Literal Corp. and Sony Corp. of America, are based on magneto-optical recording, in which data is recorded by using a laser to heat a recording spot on the disc while subjecting it to a magnetic field. The only difference between erasable and WORM discs in these systems is that the WORM disc is write-protected by putting a code on a special track.

MORE BITS IN. Input devices, too, are keeping up with higher-resolution screens. Mice, track balls, and digitizer tablets are all sporting higher resolutions, and some manufacturers, such as Mouse Systems Corp. and MicroSpeed Inc., are now targeting high-end workstations from Sun. With digitizer tablets, the trend is also to higher resolution; Summagraphics Corp. recently introduced a system with about 80-line-per-millimeter resolution.

Notebook computers have caused many engineers to give pressure-sensitive-pen digitizers a second look. While they are not yet a "plug and play" solution for desktop workstations (in notebooks, the display and drawing surface are combined), the allure of using the most common form of data recording device—a pen—to electronically capture and alter information is extremely strong.

In some applications, engineers need to use a digitizer tablet only occasionally. Their difficulty is that a typical digitizer tablet permanently takes up 900 cm² or more of desk space; that is acceptable when the tablet is being used, but it is unacceptable when it is not being used. GTCO Corp. has come up with a novel solution to this problem: a digitizer pad that rolls up so it can be stored in a drawer or a cubbyhole when not in use.

With the growth of visualization and multimedia high-resolution, color displays will soon be needed on practically every engineering desk. Once the province of high-end workstations, such as those from Silicon Graphics Inc., the quality color display is now appearing on high-end Macintoshes, PCs, and compatibles.

MORE BITS OUT. Under the Amdek label, Wyse Technology Inc. is offering a 17-inch-diagonal, 1280-by-1024-pixel, noninterlaced display that is compatible with both Macintoshes and PCs for only $1299, while Radius is marketing a 20-inch-diagonal unit whose resolution can be switched on the fly. The latter capability allows users to trade off resolution and drawing speed.

To capture the photorealistic images displayed on such monitors, high-quality graphics printers are making their way into engineering offices. The RasterOps' CorrectPrint 300, which employs a dye sublimation process, takes advantage of RISC processing to speed up the creation of quality color prints. Since such printers are fairly expensive (around $10 000), they are more likely to be used as network resources than as dedicated workstation peripherals. ◆

ICs: the brains of a workstation

Fast central processors need a supporting team of complementary chips, including graphics, I/O, and cache memory ICs

The falling prices and soaring performance of workstations are due to constantly improving IC technology. Of most visible benefit to the machines is the faster raw processing provided by new central processing units (CPUs). However, without appropriate support ICs, a fast CPU chip will not mean a fast workstation, and suppliers have therefore introduced a variety of new graphics, I/O, memory, and other chips to complement powerful new CPUs.

The heart of the workstation, all the same, is the CPU. Both reduced- and complex-instruction-set computer (RISC and CISC) technologies are vying for CPU dominance. Two currently popular CISC workstation CPUs are Intel Corp.'s 80486 and Motorola Inc.'s 68040. Both are members of architectural families that have evolved from personal computer CPUs (from the 8088 in the IBM PC and the 68000 in the Apple MacIntosh). In fact, the 68000 family was used in many workstations before the emergence of RISC architectures. Because of their use in personal computers, far more CISC CPUs are in service than RISC CPUs. This gives CISC technology the advantage of a huge, inexpensive software base. Further, the next generation of CISC chips has adopted RISC-like features. For example, the soon-to-be-introduced Intel 80586 reportedly employs pipelining, multiple-function units, and a large register set to boost its performance.

While CISC architectures have personal computer roots, RISC architectures have for the most part been designed with workstation applications in mind. Two of the most widely used are the MIPS architecture, from MIPS Computer Systems Inc., Sunnyvale, Calif., and the Sparc architecture, from Sun Microsystems Inc., Mountain View, Calif. MIPS and Sparc microprocessors are available from several IC manufacturers.

Philip Koopman Jr.
United Technologies Research Center
Daniel Siewiorek Carnegie Mellon University

An alliance among IBM, Apple Computer, and Motorola may lead to multisourcing of IBM's RS/6000 workstation microprocessor. Intergraph's Clipper, Intel's i860, and Motorola's 88000 RISC microprocessors are other popular, commercially available workstation CPUs. Hewlett-Packard's proprietary Precision Architecture (PA) is also extensively used.

LIFE CYCLE. Most future workstation CPUs are expected to be faster versions of existing architectures, with current CPU designs gradually relegated to PC-class machines. For example, Sun has announced the Sparc Lightning to supersede current Sparc implementations, and MIPS has announced the R4000 to supersede the R3000. (A workstation based on the R4000 was recently announced.) An exception is Digital Equipment Corp.'s announcement that it will introduce an entirely new RISC architecture, code-named Alpha, in a variety of products including workstations, which it will license to chip manufacturers.

As CPU chip clock frequency increases, printed-circuit board (PCB) technology has not kept pace. Thus some chip designers are running the CPU internal clock at twice the circuit board clock rate to maintain the historical 30 percent annual increase in workstation performance. Recent system designs allow the replacement of CPU chips with a pin-compatible double-frequency chip offering users a low-cost upgrade path.

Some RISC CPUs were marketed for a time as workstation CPUs but are now finding their main applications as embedded controllers. In particular, the 29000 from Advanced Micro Devices Inc. is quite successful as an X-terminal and laser printer controller. Other RISC CPUs that have small shares of the workstation market are also being retargeted to embedded use—the Motorola 88000, for one, is being used for automotive applications.

MEMORY HIERARCHY. These increasingly fast CPUs process more instructions per second, and must therefore access memory more often to obtain instructions and data. In a RISC workstation that is attempting to execute one instruction on every clock cycle, the CPU must fetch an instruction and possibly data on every clock cycle. Unfortunately, dynamic RAM speeds have not kept pace with explosive growth in CPU demands for memory accesses, and typical main memory accesses take several clock cycles. So, to prevent time-consuming stalls for every instruction, cache memories are used to speed up memory response.

Cache memories are made from relatively small, fast static RAMs that store instructions and data in heavy use; workstation main memories usually have 8–32M-byte capacity, cache memories are most often 64–256K bytes. The first time a cache miss occurs—that is, the CPU requests a data or instruction item that is not in the cache—the item is copied from main memory to the cache over several clock cycles. Once the item is in cache, it is available in a single clock cycle, and the cache scores a hit the next time the CPU requests it.

HIT OR MISS. Cache hit rates vary, but typically range from 80 to 99 percent. With high hit rates, caches can supply information fast enough to keep the CPU busy. Those performing scientific visualization and other data-intensive tasks should beware of small caches that cannot hold their large data sets effectively.

Some CPUs, including most MIPS chip implementations, have separate caches for instructions and data, so that both caches can be accessed in parallel on every clock cycle. Other CPUs, including many Sparc implementations, use a single cache for both data and instructions.

What dynamic RAMs lack in speed is being made up by cost-effective capacity. Main memory technology is quickly improving in size, with 4M-bit dynamic RAMs now in common use. Memory devices increase in capacity by a factor of four every three years with a roughly proportional decrease in cost per bit. Half the cost of a workstation may be in its memory, so price-per-bit reductions slash workstation cost.

Larger affordable main memories mean that bigger programs can fit entirely in memory, reducing delays caused by virtual memory paging. And for multitasking window environments, several tasks can reside in main memory instead of being transferred inefficiently to and from disk. Moreover, large dynamic RAMs in disk-drive controllers can be used as disk caches to speed access to frequently used disk data.

HIGHER INTEGRATION LEVELS. In all devices, the trend is to higher levels of system integration, with more functions or capacity on each chip. This trend reduces system cost and increases system reliability. Equally important, it also increases speed because on-chip connections are shorter and many interchip connections are eliminated. Above about 30–50 MHz, it becomes very difficult

to transmit signals between ICs on a printed circuit board. So, when functions cannot be integrated on one chip with today's technology, some manufacturers are producing multichip modules, where several chips are placed close together in a single package that provides a carefully designed, controlled interconnection. An example is Intergraph Corp.'s Clipper chip set. On multichip modules, large static RAMs can be quickly accessed by the CPU as cache memory.

Meanwhile, examples of highly integrated microprocessors abound. Since the introduction in 1989 of the first CPU with 1 million transistors, Intel's i860, several CPUs with even more transistors on a single chip have become available. The newest CISC processors, Motorola's 68040 and Intel's 80486, are versions of previous generations, updated to incorporate floating-point coprocessors and cache memory. A similar trend is evident in RISC CPUs.

Intel, for one, plans to double the internal clock frequency on the 80486 to speed up its operation while keeping the external circuit board transfer speed the same. The effectiveness of this strategy will depend to a large degree on the hit ratio of the on-chip cache, which varies with the application.

NEW ARCHITECTURES. Traditional CPUs can issue—at most—only one instruction per clock cycle. But three new techniques, already implemented on a few chips, may catch on because they increase that rate.

For example, superpipelined CPUs issue multiple instructions every clock cycle by

Representative ICs used in workstations

Company	Model	Unit cost, US $	Category	Performance	Two key features	Comments
AT&T Microelectronics	V.32-V42L modem chip set	$105 (10 000 qty)	Peripheral IC	Data transfer: 38.4 kb/s Fax transfer: 9.6 kb/s Power consumption: 800 mW	High speed, low power for laptops	Greatly reduces phone charges associated with modem transfer of large files (images, spread sheets, databases)
Cypress Semiconductor Corp.	CYM6002 module	$3200	RISC CPU	Specmarks: 43 Clock: 40 MHz	Complete integer and floating-point Sparc engine; on-chip cache	Two modules constitute a full four-processor Sparc multiprocessor
Cyrix Corp.	83087-33	$239	Coprocessor	Benchmarks (kWhetsone/s): double/single precision, 727/895; double/single scale, 1543/1613 Clock: 33 MHz	Floating-point operations in hardware; automatic idle mode for portables	IEEE 754-1990 compatible
Fujitsu Microelectronics Inc.	MB86903	$250 (33 MHz) $280 (40 MHz) (1000 qty)	RISC CPU	Specmarks: 25 Peak and sustained MIPS: 40 and 29 Sustained MFlops: 47 Clock: 40 MHz	Combines a high-performance, 32-bit interface unit with advanced floating-point capability	Sparc-compatible processor
Hitachi America Ltd.	HM62A-9128	$49 (1000 qty)	Cache IC	Cycle time: 16.6 ns Active power: 80 mW Clock: 60 MHz	Fully synchronized and pipelined read with output register; self-timed write; block array architecture	128K×9-bit static RAM; 60-MHz ac specification compatible with Sun advanced Sparc; 32-pin SOJ package
Intel Corp.	i4860X	$610 (1000 qty)	CISC CPU	Specmarks: 28 Dhrystone MIPS: 41 Clock: 50 MHz	On-chip FPU, 8K-byte cache; RISC integer core	IBM PC-compatible
Intergraph Corp. (Advanced Processor Division)	C4 chip set	$1000 (CPU and FPU, 1000 qty)	RISC CPU	Specmarks: 40 DP Linpack: 12 MFlops MIPS: 40 Clock: 40 MHz	Superscalar, superpipelined architectures	Upwardly compatible with C100/C300 Clipper chips
LSI Logic Corp.	LR 33020 GraphX processor	$129 (25 MHz) $161 (33 MHz) $217 (40 MHz)	Embedded RISC CPU/ graphics IC	Peak MIPS: 40 Sustained MIPS: 30+ Clock: 40 MHz	On-chip bitblit coprocessor; 4K-byte instruction cache, 1K-byte data cache	MIPS-compatible CPU
Motorola Inc.	68040	Contact supplier	CISC CPU	17–29 MIPS	Dual on-chip 4K-byte caches, on-chip FPU	68000 compatibility
National Semiconductor Inc.	DS3886A	$7 (1000 qty)	I/O IC	Propagation delay: 5 ns I_{cc} = 60 mA	Backplane transceiver logic	Bus driver, Futurebus compliant
Performance Semiconductor Inc.	PR3400	Contact supplier	RISC CPU	Specmarks: 32.4 Clock: 40 MHz	On-chip FPU; 1× clock input	MIPS instruction set standard
Philips Semiconductors–Signetics	FB2000	Depends on configuration	I/O IC	Data rate of 20 megatransfers/s for compelled mode	Supports IEEE 896 FBT+ protocol and arbitration requirements	Transceivers compatible with IEEE 1194 BTL specification
Ross Technology Inc.	CY7C605	Contact supplier	Cache IC	64-entry translation look-aside buffer; 2K-bit virtual cache tag; 2K-bit physical tag	Concurrent bus snooping, direct data intervention, and reflective memory, multiprocessing	Cache controller memory management unit; MBus, Sparc compatibility
VLSI Technology Inc.	VGC453	Contact supplier	ASIC	330-MHz flip-flop toggle frequency (worst case); 205-ps typical internal 1×, two-input NAND gate delay with two standard loads; 2.2-ns I/O pair delay (worst case)	0.8-μm silicon gate design rules; triple-metal, CMOS process	Gate array with maximum layout efficiency of 70%; 16 array sizes with a maximum of 232 300 gates; up to 434 wire-bonded or 512 TAB I/Os

ASIC = application-specific IC; bitblit = bit-aligned block transfer; CPU = central processing unit; CISC = complex-instruction-set computer; DP Linpack = double-precision linear programming package; FPU = floating-point unit; Flops = floating-point operations/s; MIPS = million instructions/s; RISC = reduced-instruction-set computer; SOJ = small outline with J leads; TAB = tape automated bonded.

breaking every CPU pipeline stage—such as instruction fetch, arithmetic and logic unit, memory access, and result store—into substages. For two substages, one instruction is issued in the first half of a clock cycle, and another instruction in the second half. At any time, one instruction is in each half of a pipeline stage. Processing speed can thus be doubled. However, the compiler must ensure that sequential instructions do not depend on each other for results or stalls will occur. The next-generation MIPS CPU, the R4000, uses superpipelining.

Superscalar CPUs, on the other hand, issue multiple instructions simultaneously to separate functional units within the CPU. For example, a CPU might be able to issue one instruction in each of three groups (such as integer operation, floating-point operation, and conditional branch) in a single clock cycle. However, if a long sequence of one type of instruction is encountered, the CPU might be able to issue only one instruction per clock cycle. While superscalar hardware can speed up existing programs, performance may be greatly enhanced by compilers that group instructions into packets containing an assortment of instruction types. Intel's i960CA RISC chip, introduced in 1991, was the first commercially available superscalar processor, but is now targeted for embedded control applications. The i960CA is typically credited with 1.2 to 1.5 instructions per clock cycle out of a maximum of three instructions per clock cycle possible. IBM Corp.'s RS/6000 is a superscalar workstation CPU, as is Sun's new Sparc Lightning chip.

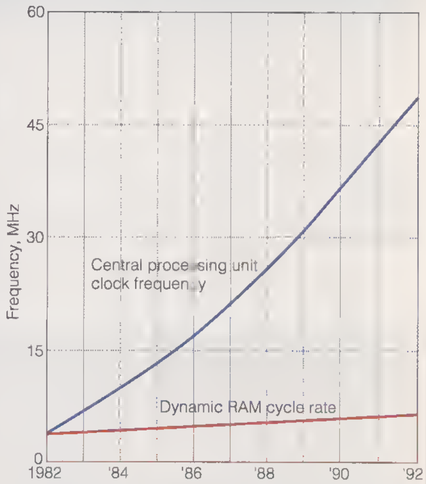
Long-instruction-word CPUs are similar to superscalar CPUs in that they issue multiple instructions in a single clock cycle. However, unlike superscalar CPUs, the compiler must do all the work instead of the hardware. In the Intel i860, for example, integer and floating-point instructions may be paired by the compiler for simultaneous issue, yielding up to two instructions per clock cycle. Again, the number of instructions per clock cycle in a long-instruction-word CPU depends heavily on the application and the compiler technology, but should be roughly equivalent to what is possible with a superscalar processor.

Another way to increase speed is to use specialized chips to help with CPU-intensive functions. For example, a workstation offered by NeXT Inc., Palo Alto, Calif., uses Motorola's M56001 digital signal-processing (DSP) chip to process high-quality audio in real time. While DSP chips will not become standard equipment on workstations for a few years, coprocessor boards based on such DSP chips as the Motorola M56000, AT&T DSP32C, and Texas Instruments 320C30 families are available as options.

Workstation peripherals also benefit from the improved performance and lower cost of higher levels of integration. In particular, advances in disk drive controller ICs and network communication ICs have produced smaller and less expensive systems. An example is an Ethernet adapter that cost about $300 a year ago in a multichip package but today costs about $100 as a single chip.

Flash electrically erasable programmable read-only memories (EEPROMs) allow erasing and rewriting of memory pages. Falling costs of EEPROMs make solid-state replacements for electromechanical disks practical. Portable computers will weigh less and their batteries will last longer as a result.

ICs AND THE WORKSTATION BUYER. Whether the ICs used inside a workstation matter to a purchaser depends on several factors. The IC of primary interest is, of course, the CPU.



While the clock frequencies of microprocessors in workstations have soared, the read-write cycle rates of dynamic random-access memories have risen only slightly.

The most important question is usually "Are important application programs readily available for my CPU?" Even though standard high-level-language compilers are available to ease the chore of transferring programs between CPU families, problems are never completely eliminated for either commercial developers or in-house programs.

Overall workstation performance depends on a variety of ICs, from the CPU to the memory chips. So whole-system performance benchmarks, such as Specmarks, are probably better indicators of performance than the type or speed of any particular IC in the system. However, if your needs do not closely match the assumptions behind the standard benchmarks, then you should pay attention to how ICs are used in the system.

ABOUT THE AUTHORS. Philip J. Koopman Jr. [M] is a senior research engineer at United Technologies Research Center in East Hartford, Conn. He works in the Advanced Digital Systems group supporting Otis, Norden, Pratt & Whitney, and other United Technologies divisions.

Daniel P. Siewiorek [F] is a professor in the School of Computer Science and the Department of Electrical and Computer Engineering at Carnegie Mellon University. He is also director of Carnegie Mellon's Design for Manufacturing Laboratory. ◆

Managing networked workstations

Standardized network management tools are now a necessity as users mix and match equipment from different vendors

A server on the workstation network you manage failed suddenly yesterday morning. With the help of the server vendor, you identified the cause as a bug in a device driver. The vendor rushed you a diskette with an update of that system software, which you have just finished installing and testing. As the vendor promised, it solved the problem.

Terrific, except that your company installed that device driver on more than 100 of its machines over the past year. Which ones? And how can you get the new software onto them without spending a fortune? After all, some of your nodes are halfway around the world. And how do you schedule the upgrade and test it without causing additional problems?

Those are just a few of the questions managers of networked workstations and other distributed computing systems continually ask themselves. For although software does exist that can help them do their jobs, it consists mainly of incompatible bits and pieces.

THE PROBLEM. The trouble is that until recently, most system and network management products were specific to only one vendor's products, but as users have interconnected equipment from multiple vendors, managers must now oversee a heterogeneous distributed system involving diverse sets of managed resources.

These include users and user groups, operating system and application software, workstation and server hardware, databases, and printers and printer queues. Because the systems management tools for this category typically use nonstandard management protocols, administrators are limited by the systems management applications available for each product.

Among those applications are configuring and installing software on workstations, monitoring network and server performance, controlling remote workstations, detecting and fixing problems, and implementing security measures [see table]. They can be broken down into eight categories:

- **Configuration management,** which deals with the addition, deletion, modification, distribution, and browsing of managed resources. It may include creating a set of policies that spans a set of networked machines, distributing and customizing software for the networked workstations, and setting up a printer or print queue on a server. The distribution of software is often singled out as the following separate category.
- **Change management**, which introduces structure and policy to the distribution of operating system software, application software, and data files. Change management software allows an administrator to plan and distribute updates across the network to the workstations and servers. Afterward, the changes can be tested and even undone if the test fails.
- **Problem management,** which deals with detecting managed resource faults and notifying the appropriate administrators. It also deals with managing problem reports submitted by end users. Problem management frequently includes automatic program execution to fix or bypass specific faults—as when an end user or program reports that a certain system function is not available.
- **Operations management,** which concerns the (remote) control of managed resources in a distributed system. Examples include stopping and restarting specific applications software and rebooting a workstation. Most software packages combine operations management and problem management in one product.
- **Performance management,** which deals with monitoring managed resources for overload and notifying the appropriate administrators or taking automatic action—for example, monitoring file systems for a disk that is 85 percent full or monitoring for overloaded print queues.
- **Accounting management,** which covers accounting and billing for the use of managed resources. Examples include keeping track of how many licenses have been granted to users, enforcing network licenses, and accounting for disk or central processing unit usage on a server machine.
- **Security management,** which deals with authenticating and authorizing accesses to a managed resource. An example might be assigning and checking the privileges of a person who wants to use a printer. This category also deals with putting "firewalls" around sensitive resources—for instance, securing a host to prevent remote log-ins.
- **Backup/restore management,** which deals with the recovery from disk failure as well as the rollback to previous versions of files to recover data or programs that were lost because of user error.

THE SOLUTION. To simplify the administration of distributed systems—indeed, to make that work practical—a consistent and unified approach is necessary to manage heterogeneous distributed systems. Without it, companies are faced with the specter of administration expenses that can exceed the original costs of their systems.

In an effort to provide the desperately needed consistency and interoperability, industry consortia, standards organizations, and individual companies are taking a variety of actions.

For example, the Open Software Foundation (OSF/USA) in Cambridge, Mass., is addressing the distributed management problem through its distributed management environment (DME) offerings, which will provide a common management infrastructure for building distributed systems and network management applications. The infrastructure is based on an object-oriented approach and it includes support for standards-based technology.

The DME will also provide an initial set of applications in the areas of host, print, software licensing, and software distribution management. It includes technologies developed by Tivoli Systems, Hewlett-Packard, IBM, Groupe Bull, Gradient Technologies, Banyan Systems, and the Massachusetts Institute of Technology.

Already the DME integration effort is under way, and first delivery of source code of the integrated offering is expected in 1993. When it is delivered, vendors will be able to take the OSF/DME code and build systems and network management products.

Another consortium, Unix International (UI), in Parsippany, N.J., through its System Management Work Group (SMWG), has defined its requirements for a distributed system and network management framework. Now an integral part of the UI Atlas architecture, the framework revolves around a common object model and the application object platform that supports the model.

UI endorsed Tivoli Systems Inc.'s WizDOM as an existing product that satisfies the framework requirements [see table]. To implement those requirements, Unix Software

L. Brooks Hickerson and Cheryl S. Pervier IBM Corp.
Peter Valdes Tivoli Systems Inc.

Laboratories (USL) early this year joined with Tivoli to develop the framework on top of System V R4. A first snapshot of the framework is expected late this year.

Among other groups is X/Open, headquartered in High Wycombe, Bucks., England. Through its System Management Program (XSM), it is defining a reference model based on the open systems interface (OSI) management model. The reference model focuses on the management interaction between programs acting as agents.

The XSM will also provide interface specifications and guidelines for defining managed objects that support its reference model. The program uses object-oriented techniques in specifying the structure of its management information. These techniques, based on the OSI model, are expected to be harmonized with the emerging standards of the Object Management Group (OMG) discussed below.

A consortium of information technology vendors, the Network Management Forum, Bernardsville, N.J., aims to accelerate the development and use of interoperable network management products. It also seeks to support the migration of those products to meet international standards. To date, the forum has produced specifications that cover, among other things, an object specification framework for defining managed objects, and a library of managed object definitions.

REVOLVING SPECIFICATIONS. The Internet Advisory Board (IAB), an informal group, focuses on producing standard specifications revolving around the internet protocol suite, the SNMP, the structure of management information (SMI), and the management information base (MIB) used in managing internets based on transmission control protocol/internet protocol (TCP/IP).

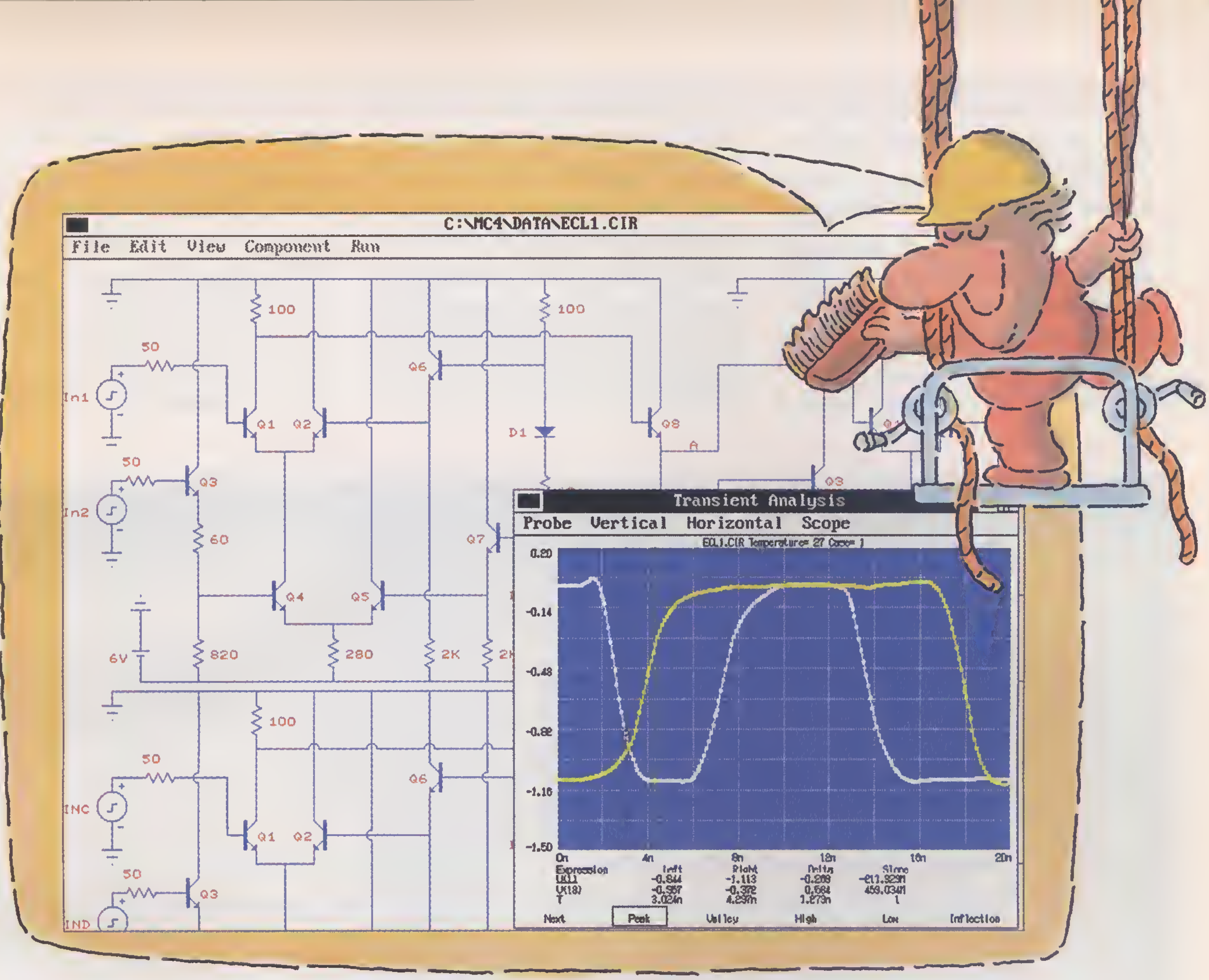
The specifications are published in what are known as requests for comments (RFCs). For example, the SNMP (RFC 1157) is a simple-minded protocol aimed at getting and setting variables on managed resources. The Internet SMI is specified in RFC 1155, and a set of internet-based managed objects (called MIB-II) is specified in RFC 1213.

Within the IEEE, the Posix Standards Committee on System Administration, known as P1003.7, is working on defining standards for managing heterogeneous distributed systems. The reference model defined by P1003.7, which is in many respects in alignment with the XSM reference model, is based on the concepts of tasks, managed objects, common services provided by a management framework, and the interaction of tasks with other tasks, managed objects, and the framework.

The goal of P1003.7 is to standardize the command line interface (CLI), programmatic interface, and managed object definitions supporting a number of important system administration tasks. The group is currently working on standardizing tasks related to print, software, user, and user group management.

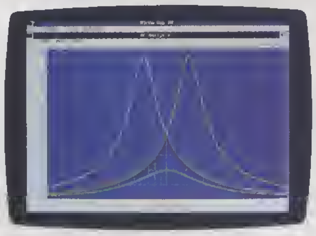
Another group, the International Standards Organization (ISO), based in Geneva, Switzerland, has produced a number of specifications revolving around the management and interoperability of OSI-based networks through its SC21 X3T5 Standards Committee. The specifications cover, among other things, a management framework (ISO/IEC 7498-4), CMIS/P (ISO/IEC 9595/9596), the OSI structure of management information (ISO/IEC 10165), guidelines for the definition of managed objects or GDMO (ISO/IEC 10165-4), and a number of specifications covering various system management functions (under various ISO/IEC 10164-X documents). The OSI SMI and GDMO provide an object-oriented schema for specifying OSI management information. (IEC stands for the International Electrotechnical Commission.)

Finally, the Object Management Group (OMG), based in Framingham, Mass., is a consortium of companies interested in defining object standards and promoting object technology. The work of the OMG is not directly related to system and network management, but other consortia—like the OSF, UI, and X/Open, directly involved with



INTRODUCING MICRO-CAP IV.™ MORE SPICE. MORE SPEED. MORE CIRCUIT.

PC-based circuit analysis just became faster. More powerful. And a lot easier. Because MICRO-CAP IV is here. And it continues a 12-year tradition of setting CAE price/performance standards.



AC Analysis

Put our 386/486 MICRO-CAP IV to work, and you'll quickly streamline circuit creation, simulation and edit-simulate cycles — on circuits as large as 10,000 nodes. In fact, even our 286 version delivers a quantum leap upward in speed. Because, for one thing, MICRO-CAP IV ends SPICE-file-related slowdowns; it reads, writes and analyzes SPICE text files and MC4 schematic files. It also features fully integrated schematic and text editors. Plus an interactive graphical interface — windows, pull-down menus, mouse support, on-line HELP and documentation — that boosts speed even higher.

Now sample MICRO-CAP IV power. It comes, for example, from SPICE 2G.6 models plus extensions. Comprehensive analog behavioral modeling capabilities. A massive model library. Instant feedback plotting from real-time waveform displays. Direct schematic waveform probing. Support for both Super and Extended VGA.

And the best is still less. At $2495, MICRO-CAP outperforms comparable PC-based analog simulators — even those $5000+ packages — with power to spare. Further, it's available for Macintosh as well as for IBM PCs. Write or call for a brochure and demo disk. And experience firsthand added SPICE and higher speed — on larger circuits.

Spectrum
1021 S. Wolfe Road
Sunnyvale, CA 94086
(408) 738-4387 FAX (408) 738-4702

Circle No. 217

such management—are becoming more interested in using the group's specifications in implementing object-oriented distributed management applications.

So what does all of this mean in terms of the flawed device driver that is still threatening your systems across the nation and around the world? If you have systems management software that includes change, configuration, operations, and problem management; if that software can operate in all your systems; and if it has connectivity to them, it means that you are in luck.

In that case, you can simply sit down at your graphics console, review the systems that are currently running the driver, and check that each has the hardware and software needed to support the updated version. Then you schedule an update for midnight tonight, and you select test programs to run after the update in order to verify that all went well.

While you sleep, your systems will be updated and tested. If anything goes wrong, the changes will be backed out and the original software restored. Tomorrow morning you can review the error logs and check the version numbers of the drivers to make sure the job was correctly done. And then you can have your morning cup of coffee.

ABOUT THE AUTHORS. L. Brooks Hickerson is a senior technical staff member and OS/2 system management architect, and Cheryl S. Pervier is an advisory programmer, AIX systems management architecture, at IBM Corp., Austin, Texas.

Peter Valdes is responsible for product architecture and standards at Tivoli Systems Inc., Austin, Texas, a company he founded. He is active in IEEE Posix as well as in industry consortia involved in standards for network management. ◆

Representative system management software for networked workstations

Company	Product	Unit cost, US $	Platform (operating system)	Protocols used	Managed resources	Management applications	Comments
Agorus SA	Auditor	$2400	RS/6000 (Aix 3.2), DPX (BOS, SPIX)	CCS/SM, TCP/IP	OS, file-server, user applications software	Configuration, operations, performance, remote work	A graphical application for remotely managing multiple OSs
Digital Equipment Corp.	DECmcc Management Station for Ultrix	$7070	DECstation 5000; VAX station 3100	DECnet Phase IV, ELMS, MOPS	Bridges, routers, comm. cards, W&P hardware	Configuration, fault, operations, performance	Employs remote bridge management software for managing FDOI systems
Hewlett-Packard Co.	OperView Network Node Manager 2.0	$15 000	HP9000, SunSparc	SNMP, TCP/IP	Bridges, routers, comm. cards; OS, file-server, and user application software	Configuration, fault, performance	A graphical application for managing TCP/IP networks with SNMP devices
IBM Corp.	NetView/6000	$14 900	RS/6000 (AIX 3.2)	SNMP	Bridges, routers, gateways, comm. cards; OS software; W&P hardware	Configuration, fault, performance	Monitors any IP addressable node and manages any system with SNMP agent[b]
Intergraph Corp.	Network Management System	$15 500	Clipper	SNMP	Bridges, routers, hub[a]; terminal server and W&S hardware	Configuration, fault, performance; discovery of TCP/IP nodes	Manages any TCP/IP-addressable node or system with an SNMP agent[b]
NCR Corp.	StarSentry Systems Manager	$15 000	NCR System 3000, Model 3445	CMOT, SNMP, UOP, TCP/IP, LU6.2	Bridges, routers, hub[a]; comm. cards; network OSs; W&P hardware	Configuration, fault, client, performance, Unix; software distribution	—
Siemens Nixdorf AG	Transview SNMP	Contact vendor	MX 300, MX 500, RM 400, RM 600, WX 200	SNMP	Bridges, routers, hub,[a] comm. cards, OS software	Configuration, fault, performance	—
Tivoli Systems Inc.	WizDOM Primary Resource Management	$20 000 and up	Sun 3; Sparcstations and compatibles	UDP/IP	Individual users, groups, hosts, and network information services	General system management and administration	For distributed systems administration under Unix; built upon Tivoli's object-oriented framework[c]
UniSolutions Associates	SysAdmin	$2000–$6000	Sun, DEC, HP	TCP/IP, RPC/XOR	OS, file server, and user application software; W&P hardware	Operations, performance, remote work; software distribution	Also manages backup, restore, and archive functions and users accounts, and monitors performance

a Hub: a system that connects several nodes in a star configuration.
b Agent: software that provides information about a managed system in which it resides.
c Framework: a set of common object, application, and management services that build on basic operation system services.

CCS/SM = common command set for system management
CMIP or CMIS = common management information protocol or service
CMOT = CMIP on TCP/IP networks
comm. = communications
ELMS = extended local-area network management software
FOOI = fiber distributed data interface
LU6.2 = logical unit 6.2, part of SNA
MOPS = maintenance protocol for terminal services
OS = operating system
RPC/XDR = remote procedure call/external data presentation
SNA = systems network architecture
SNMP = simple network management protocol
TCP/IP = transmission control protocol/internet protocol
UDP/IP = user Datagram protocol/Internet protocol
W&P or W&S = workstation and peripheral or server

To probe further

For a complimentary copy of the *Executive Summary and Report on Spectrum's Workstation Market Survey*, contact Arthur C. Nigro, Marketing Director, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7298; fax, 212-705-7453.

CONFERENCES. The International Solid-State Circuits Conference (ISSCC) has become a showcase for the latest workstation chips and the technologies behind them. The proceedings of the 39th ISSCC, held in February at the San Francisco Hilton Hotel (IEEE Cat. No. 92CH3128-6), are available from the IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-981-0060.

Also, the Microprocessor Forum covers late-breaking developments in chips for workstations and other equipment. Proceedings of the most recent forum, held Nov. 6–7, 1991, are available from MicroDesign Resources, 874 Gravenstein Highway S., Suite 14, Sebastopol, Calif. 95472; 707-823-4004; fax, 707-823-0504.

From June 8 to 12 in Anaheim, Calif., the 1992 29th Association for Computing Machinery (ACM) and IEEE Design Automation Conference will feature electronic design tools for workstations. Contact: IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

Network management will be addressed in the 1992 IEEE Network Operations and Management Symposium—NOMS '92—in Memphis, Tenn., April 6–9. Contact: Jill Pancio, Pacific Bell, 7620 Convoy Court, San Diego, Calif. 92111; 619-268-6135; fax, 619-292-1509.

PUBLISHED WORKS. *MIPS RISC Architecture*, by Gerry Kane and Joe Heinrich (Prentice Hall, 1992), gives a detailed description of reduced-instruction-set computer (RISC) architecture developed by MIPS Computer Systems and available in hardware from a number of IC manufacturers. Particular attention is given to the latest design, the R4000.

Reliability data on leading workstations and peripherals brands are available from Reliability Ratings Inc., Needham, Mass., at an annual subscription rate of US $395. Contact: Reliability Ratings, 163 Highland Ave., Needham, Mass.; 800-477-RELY (United States only) or 617-444-5755; fax, 617-444-8958. ◆

Acknowledgments

In preparing this special report, *IEEE Spectrum* called on many experts. We are especially indebted to the individuals listed below for their advice and guidance, although their identification with the report should not be construed as their endorsement of any opinions or products covered, nor the statements made.

The advisers for this report were: Ronald P. Bianchini, assistant professor, department of electrical and computer engineering, Carnegie Mellon University, Pittsburgh; Kjell Carlsen, director, engineering computing and analysis, Boeing Computer Services Co., Bellevue, Wash.; Grant Martin, manager, VLSI Design Systems, Bell-Northern Research, Ottawa, Ont. Canada; Roland Mercier, professor, State University in Paris-Nanterre, France; Reddy Penumalli, CAD manager, Analog Devices Inc., Wilmington, Mass.; and Warren Snapp, Manager, Semiconductor Design and ASIC Design Center, Boeing Defense and Space Group, Kent, Wash.

Index

Listed below are companies whose products or software packages are tabulated in this report; a list of advertisers follows. Page numbers in the editorial index refer to the beginnings of the tables in which the products appear. In the advertisers' index they refer to the locations of the advertisement. To obtain more information from a company, circle its associated number on the reader service card facing p. 34.

EDITORIAL

WORKSTATIONS, p. 40

X TERMINALS, p. 42

ADD-DNS AND PERIPHERALS, p. 47

Pliceon Inc., Helios Systems Div., 1996 Lundy Ave., San Jose, CA 95131, 408-432-0292:
interface and expander boards **circle no. 351**
memory boards **circle no. 352**
Racal-Datacom Inc., LAN Internetworking Div., 155 Swanson Rd., 8oxborough, MA 01719, 508-263-9929, 800-LAN-TALK: local-area networks **circle no. 353**
Radius Inc., 1710 Fortune Dr., San Jose, CA 95131, 408-434-1010:
hardware accelerators and coprocessors **circle no. 354**
graphics adapters **circle no. 355**
high-resolution monitors **circle no. 356**
RasterOps Corp., 2500 Walsh Ave., Santa Clara, CA 95051, 801-226-5265:
hardware accelerators and coprocessors **circle no. 357**
graphics adapters **circle no. 358**
high-resolution monitors **circle no. 359**
graphics printers **circle no. 36D**
Rexon Inc., Tecmar subsidiary, 6225 Cochran Rd., Solon, DH 44139, 800-624-8560:
memory boards **circle no. 361**
erasable optical drives **circle no. 362**
magnetic-tape drives **circle no. 363**
Wangtek Inc., 41 Moreland Rd., Simi Valley, CA 93065, 805-583-5255: magnetic-tape drives **circle no. 364**
RG8 Spectrum, 950 Marina Village Pkwy., Alameda, CA 94501, 510-848-0180:
graphics adapters **circle no. 365**
scan converters **circle no. 366**
Science Accessories Corp., 200 Watson 8lvd., Stratford, CT 06497, 203-386-9978: digitizer tablets **circle no. 367**
Scriptel Corp., 4145 Arlingate Plaza, Columbus, OH 43228, 614-276-8402: digitizer tablets **circle no. 368**
SGS-Thomson Microelectronics, Inmos Div., 1310 Electronics Dr., Carrollton, TX 75006, 602-867-6259: hardware accelerators and coprocessors **circle no. 369**
SKY Computers Inc., 27 Industrial Way, Chelmsford, MA 01824, 508-250-1920: hardware accelerators and coprocessors **circle no. 37D**
SMC (Standard Microsystems Corp.), Systems Products Div., 80 Arkay Dr., Hauppauge, NY 11788, 800-SMC-4-YOU: local-area networks **circle no. 371**
Sony Corp. of America, Sony Drive, Park Ridge, NJ 07656, 201-930-6025: WORM drives **circle no. 372**
Sony Corp. of America, 655 River Oaks Pkwy., San Jose, CA 95134, 800-352-7669:
compact-disc RDM **circle no. 413**
erasable optical drives **circle no. 373**
multifunction optical-disc drives **circle no. 374**
high-resolution monitors **circle no. 375**
Spectra Logic (see **Western Automation Laboratories Inc.**)
Summagraphics Corp., Digitizer Div., 60 Silvermine Rd., Seymour, CT 06480, 203-881-2000: digitizer tablets **circle no. 376**
Houston Instrument Division, 8500 Cameron Rd., Austin, TX, 78753, 512-835-0900: pen plotters **circle no. 377**
Sysgen Inc., 556 Gibraltar Dr., Milpitas, CA 95035, 800-821-2151: magnetic-disk drives **circle no. 378**
Tecmar (see **Rexon Inc.**)
Tektronix Inc., 26600 S.W. Parkway Ave., Wilsonville, DR 97070, 800-835-6100: graphics printers **circle no. 379**
Univision Technologies Inc., Three 8urlington Woods, Burlington, MA 01803, 617-221-6700: graphics adapters **circle no. 38D**
Wacom Technology Corp., 501 S.E. Columbia Shores 8lvd., Suite 300, Vancouver, WA 98661, 206-750-8882: digitizer tablets **circle no. 381**
Wangtek Inc. (see **Rexon Inc.**)
Western Automation Laboratories Inc., 1700 N. 55th St., 8oulder, CD 80301, 303-449-6400: memory boards **circle no. 382**
Spectra Logic, a Division of Western Automation Laboratories Inc., 1700 N. 55th St., 8oulder, CO 80301, 303-449-7759: magnetic-tape drives **circle no. 383**
Winchester Technology, 3335 Kifer Rd., Santa Clara, CA 95051, 800-854-7878:
memory boards **circle no. 384**
magnetic-disk drives **circle no. 385**
Wyse Technology Inc., Amdek, 3471 N. First St., San Jose, CA 95134, 800-GET-WYSE: high-resolution monitors **circle no. 386**
Zycad Corp., 1380 Willow Rd., Menlo Park, CA 94025, 415-688-7451: hardware accelerators and coprocessors **circle no. 387**

ICs, p. 53

AT&T Microelectronics, Two Dak Way, Berkeley Heights, NJ 07922, 908-771-2000 **circle no. 388**
Cypress Semiconductor Corp., 3901 N. First St., San Jose, CA 95134, 408-943-2600 **circle no. 389**
Cyrix Corp., 2703 N. Central Expressway, Richardson, TX 75080, 214-234-8387 **circle no. 39D**
Fujitsu Microelectronics Inc., Advanced Products Div., 77 Rio Robles, San Jose, CA 95134-1807, 408-456-1000 **circle no. 391**
Hitachi America Ltd., 2000 Sierra Point Pkwy., Brisbane, CA 94005, 415-589-8300 **circle no. 392**
Intel Corp., 1900 Prairie City Rd., Folsom, CA 95630, 800-538-3373 **circle no. 393**
Intergraph Corp., Advanced Processor Div., 2400 Geng Rd., Palo Alto, CA 94303, 415-494-8800 **circle no. 394**
LSI Logic Corp., 1551 McCarthy 8lvd., Milpitas, CA 95035, 408-433-7150 **circle no. 395**
Motorola Inc., Microprocessor Products Group, 6501 William Cannon Dr. West, Austin, TX 78735-8598, 512-891-2389 **circle no. 396**
National Semiconductor Inc., 2900 Semiconductor Dr., Santa Clara, CA 95062-8090, 408-721-5000 **circle no. 397**
Performance Semiconductor Corp., 610 E. Weddell Dr., Sunnyvale, CA 94089, 408-734-8200 **circle no. 398**
Philips Semiconductors-Signetics, 811 E. Arques Ave., M/S 23, Sunnyvale, CA 94088-3409, 408-991-3626 **circle no. 399**
Ross Technology Inc., 7748 Highway 290W, #400, Austin, TX 78736, 512-448-8968 **circle no. 4DD**
VLSI Technology Inc., 1109 McKay Dr., San Jose, CA 95131, 408-434-3000 **circle no. 4D1**

NETWORK MANAGEMENT SDFTWARE, p. 58

Agorus SA, 15, rue du Buisson aux Fraises, F-91300 Massy, France, (33+1) 6930 9850 **circle no. 4D2**
Digital Equipment Corp., 110 Spit 8rook Rd., Nashua, NH 03062, 800-DIGITAL or contact your local sales office **circle no. 4D3**
Hewlett-Packard Co., contact your local sales office **circle no. 404**
IBM Corp., 3039 Cornwallis Rd., Research Triangle Park, NC 27709, 919-543-2384 **circle no. 4D5**
Intergraph Corp., One Madison Industrial, Huntsville, AL 35894, 205-730-7689 **circle no. 4D6**
NCR Corp., 3325 Platt Springs Rd., West Columbia, SC 29170, 803-796-9250 **circle no. 4D7**
Siemens Nixdorf AG, Dtto Hahn Ring 6, D 8000 Munchen 83, Germany, (49+89) 636 45444 **circle no. 408**
Tivoli Systems Inc., 6034 West Courtyard Dr., Austin, TX 78730, 800-2-TIVOLI **circle no. 409**
UniSolutions Associates, 2103 Mathews Ave., Suite. 1, Redondo 8each, CA 90278, 310-542-0068 **circle no. 41D**

ADVERTISERS

88N Systems & Technologies, 10 Moulton St., Cambridge, MA 02138, 617-873-2559 **circle no. 213, p. 34**
Bimillennium, 101 Albright Way, Los Gatos, CA 95030, 800-488-8662 **circle no. 215, p. 43**
8oeing Computer Services, 8ox 24346, MS 7L-46, Seattle, WA 98124-0346, 800-426-1443 **circle no. 214, p.62**
Cardiff Publishing Co., 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111, 303-220-0600 **circle no. 204, p. 56**
Computer Associates Inc., 1 Computer Associates Plaza, Islandia, NY 11788, 800-CALL CAI **circle no. 2D3, p. 44-45**
CSPI, 40 Linnell Circle, 8illerica, MA 01821, 800-325-3110 **circle no. 2D7, p. 51**
Datel Inc., 11 Cabot Blvd., Mansfield, MA 02048, 508-339-3000 **circle no. 2D6, p. 54**
I8M Corp., Old Orchard Road, Armonk, NY 10504, 800-426-6676. ext. 769 **p. 32-33**
Integrated Engineering Software, 347-435 Ellice Ave., Winnipeg, MAN R3B 1Y6, Canada, 204-942-5636 **circle no. 208, p. 28**
Integrated Systems Inc., 3260 Jay St., Santa Clara, CA 95054, 408-980-1500 **circle no. 2D1, p. 27**
Mathsoft Inc., 201 Broadway, Cambridge, MA 02139, 800-628-4223 **circle no. 216, p. 42**
Microway Inc., 8ox 79, Kingston, MA 02364, 508-746-7341 **circle no. 2D5, p. 29**
Modgraph Inc., 83 Second Ave., 8urlington, MA 01803, 617-229-4800 **circle no. 202, p. 61**
Numerical Algorithms Group Inc., 1400 Opus Place, Suite 200, Downers Grove, IL 60515, 708-971-2337 **circle no. 210, p. 59**
Precision Visuals Inc., 6230 Lookout Rd., 8oulder, CD 80301, 800-447-7147 **circle no. 2D9, p. 39**
Spectrum Software, 1021 South Wolfe Rd., Sunnyvale, CA 94086, 408-738-4387 **circle no. 217, p. 57**

Iraq's bomb

(Continued from p. 24)
bombed, only eight had been installed, and another 17 were in various stages of assembly. In commissioning tests, the calutrons produced about half a kilogram of uranium enriched to an average of 4 percent U-235, Zifferero said. And, according to Kay, some samples taken from Tarmiya showed enrichment levels between 20 and 30 percent U-235.

The IAEA estimates that had the Tarmiya plant gone into full operation, it could have produced up to 15 kg of highly enriched uranium a year, enough for one implosion-type bomb.

CENTRIFUGE 'BREAKTHROUGH.' Most investigators believe that the EMIS facility at Tarmiya would have been the first to yield enriched materials in quantity, but there is ample evidence, they say, that emphasis had shifted to the centrifuge program by the late 1980s. Although the program started out earlier in the decade as a relatively low-budget affair, a "breakthrough" in the late 1980s seems to have suddenly put the Iraqis on the track of a much more advanced centrifuge design. There is little doubt now that the breakthrough was the acquisition of centrifuge parts, designs, and advice from European sources.

In a centrifuge, gaseous uranium hexafluoride is spun in cylinders with diameters of about 75-400 mm. Centrifugal forces push the heavier U-238 to the cylinder wall, while the U-235 tends to collect closer to the center of the cylinder. Speeds of 400–600 meters per second at the cylinder circumference are required, and "below about 300 meters per second, you don't get any separation at all," an expert in the technology told *Spectrum*. To withstand the high speeds, the cylinders are fabricated of materials with high tensile strength, typically either carbon fiber or maraging steel. To minimize friction and maximize speed, the cylinder is spun in a vacuum.

Even at high speeds, the separation requires "cascades" of thousands of centrifuges, each of which enriches the uranium by another increment. Both the construction of the individual centrifuges and—more importantly, their arrangement into a working cascade—require considerable technological sophistication.

To enrich uranium in centrifuges, the Iraqis would also have needed the ability to produce uranium hexafluoride, a process known as fluorination. Iraq bought an aluminum fluoride production plant in the late 1970s, and apparently succeeded in converting it for use with uranium—Iraqi officials have admitted producing half a kilogram of uranium hexafluoride, and separating a small (militarily irrelevant) amount of enriched uranium in an experimental centrifuge system.

According to *The Death Lobby*, an investigative book about the Iraqi weapons program by journalist Kenneth R. Timmerman, the fluorination equipment came from Alesa Alusuisse Engineering. Timmerman also claims that the Iraqi centrifuge program began in the early 1980s with purchases of centrifuges from Brazil (which that country had obtained legally from West Germany) and with assistance from China. But by the mid-1980s, Iraq had evidently obtained all necessary design information to re-create—and even slightly improve upon—the G1 centrifuge, which was used by the European Enrichment Co. (Urenco) in the 1960s and early 1970s. IAEA and other investigators contacted by *Spectrum* say they are not sure exactly how Iraq obtained information on the centrifuge design from Urenco, a consortium of German, Dutch, and British firms that operates what are generally regarded as the world's most advanced centrifuge plants in Almelo, the Netherlands; Capenhurst in Britain; and Gronau, Germany.

In the late 1980s, the Iraqis called in Bruno Stemmler and Walter Busse, who had worked on gas centrifuges at MAN Technologie, a German member of the Urenco consortium. While insisting that he did not know the true purpose of the Iraqi centrifuges, Stemmler told the *Sunday Times* of London in December 1990 that he and Busse were hired to trouble-shoot an experimental enrichment cascade the Iraqis had set up near Tuwaitha. As of late February, the German Government was believed to be considering whether to press charges against Stemmler and Busse, but it was not clear that the two had broken any German laws. (Not until 1990 did the former West German Government make it a crime for its citizens

Standoff at Al Atheer: 'Thank God for the satellite telephone'

For a few days, tens of millions of people watched television news reports and listened to their radios, most in disbelief. Just months after suffering one of the most lopsided military defeats in history, the Iraqi Government seemed to be intent on provoking another war.

As a condition of its surrender, the Iraqi Government agreed to open its weapons facilities—especially its nuclear complex—to inspectors from the United Nations and the International Atomic Energy Agency (IAEA). But on the sixth inspection mission, the Government's attitude toward the inspectors went from spottily cooperative to openly hostile. Access was barred to key facilities, documents were seized, official communiqués were intercepted, and, in the most publicized incident, the inspection team was detained for four days in a parking lot next to an inspection site.

The trouble began the evening of the first day, Sept. 22, when the team, after collecting several dozen boxes of documents, attempted to leave the Nuclear Design Center at Al Atheer. Iraqi officials detained the 43-member team and confiscated the documents, which described Iraq's secret program to build a centrifuge plant to enrich uranium to weapons grade. The team was released after 5 hours and some of the documents were returned after 11 hours.

According to team leader David Kay, about one-quarter of the documents were not returned, however. These documents probably had information related to procurement and design of parts and materials needed for the centrifuge program, Kay said, explaining that the team's translators had scanned the documents and made a brief synopsis before the papers were confiscated.

At the second inspection site, the headquarters of the country's nuclear-weapon development facility, Iraqi officials again attempted to confiscate documents. At stake was information that Kay called "a gold mine": data on the weapons development program; information on Iraq's pursuit of four different enrichment technologies; complete personnel and payroll records of the clandestine weapons effort; and some foreign and domestic procurement records. This time, the team refused, setting up a standoff in an adjacent parking lot that lasted 96 hours.

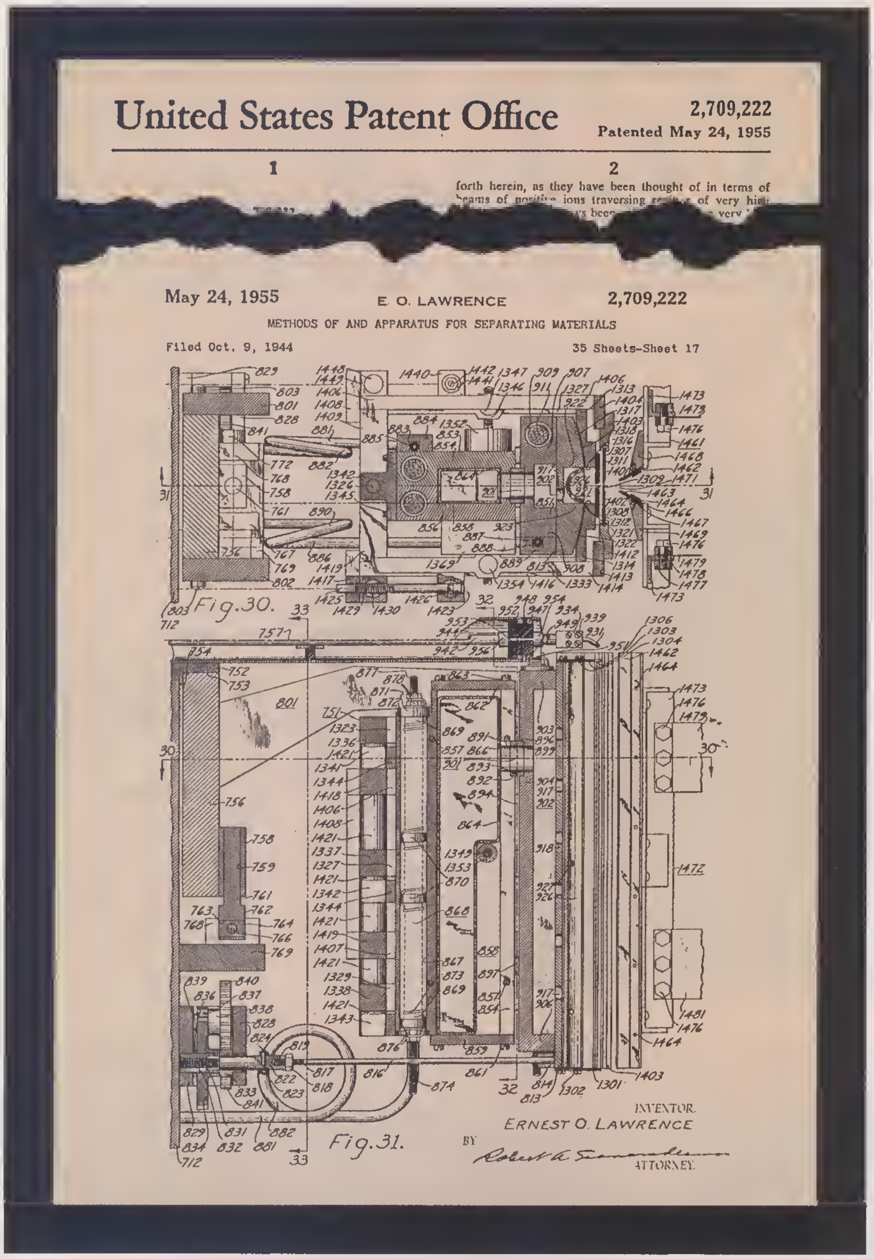
In this war of wills, the inspection team had a secret weapon of its own: a satellite telephone, which was used to do live interviews with major news organizations worldwide. Once again, in a manner bizarrely reminiscent of the Gulf War, the Iraqis "totally underestimated the impact of modern technology," Kay said in an interview. "They didn't understand how we could contact CNN and NPR [National Public Radio]," he observed.

The stalemate was to take a further "surreal" twist on the third day, when Kay, exhausted from doing interviews, heard his satellite telephone ring. It was the operator from the International Maritime Satellite (Inmarsat) Organization. Concerned about the unusual activity on Kay's line, he asked if Kay knew his satellite telephone had been in use for 20 of the last 24 hours. Kay did indeed.

Kay explained his predicament and "the guy became very helpful." In Iraq, the team's telephone was at the edge of the closest satellite's coverage, so the operator shifted the satellite in orbit to better accommodate the team. He also rerouted their traffic to an Inmarsat ground station in Australia, which was less heavily trafficked than the Indian Ocean ground station they had been going through.

Finally, at 5:46 a.m. on Sept. 28, the team was released, the disputed documents still in their possession. Relieved, Kay could not help wondering nevertheless what could have happened.

"Thank God for the satellite telephone," said Kay, now secretary general of the Uranium Institute in London. "If we had been caught out there in the parking lot without communications, it's possible that the Iraqis might have used more force than they did, and the United States could have responded militarily." —*G.Z.*



Copies of many U.S. patents and other declassified information from the Manhattan Project were among the 60 000 pages of documents found at Iraqi nuclear sites by inspectors from the International Atomic Energy Agency in Vienna. Many of the patents, such as this one, were related to electromagnetic isotope separation (EMIS), and were held by the U.S. physicist Ernest O. Lawrence. EMIS was one of several techniques Iraq had just begun using, on an experimental basis, to enrich uranium for its planned atomic bomb. The extremely inefficient method had not been used for military purposes since World War II. In the 1950s, confident that no nation would ever use the antiquated technique to build bombs, the U.S. Government declassified thousands of pages of information on EMIS.

to privately assist foreign weapons programs.)

Stemmler told the *Sunday Times* he saw equipment from many western companies during his visits to the Iraqi facility, including vacuum pumps from Veeco Instruments Inc., Plainview, N.Y., and valves, furnaces, and other equipment from VAT of Lichtenstein and Leybold-Heraus of the then West Germany. Even though sales of most of this equipment was not controlled by export laws, some of it was procured through phony intermediary companies set up in London, Germany, and elsewhere.

IAEA investigators have also found centrifuge rotors in Iraq that were produced in the former West Germany. Their shape and carbon fiber composition could have left no doubt about what the rotors were for, IAEA inspectors said. The sale of carbon-fiber centrifuge rotors was "absolutely illegal," Kay added.

Unwilling to depend on outside suppliers for parts, Iraq was building its own plant to manufacture centrifuges at Al Furat. The plant, which was still incomplete when war broke out in the Gulf, would have been capable of turning out centrifuges by the thousands, according to Thorne. Some of the most important pieces of manufacturing equipment for the plant were supplied by H & H Metallform Maschinenbau und Vertriebs GmbH of the former West Germany. The key raw material for the centrifuges was also found in Iraq: some 100 metric tons of maraging steel, most of which had been melted in an unsuccessful attempt to conceal it from inspectors. By early March, the IAEA had still not released the names of the companies that sold Iraq the maraging steel.

Although the IAEA believes that Iraq did not succeed in operating a pilot centrifuge cascade before it invaded Kuwait, Kay disagrees. "It's hard to believe that the materials for 10 000 centrifuges were ordered without having a small pilot plant going" to verify that the process would work, he said. A "small" cascade would comprise perhaps 100–500 centrifuges, he explained, adding that such a cascade would be sufficient to "tune" the system and establish the efficiency of the process. The hypothetical cascade could have been in operation late in 1989, and may have been disassembled and hidden from IAEA inspectors "until the heat is off," he said.

A key point about uranium enrichment—and one frequently overlooked in accounts of the Iraqi program—is that more than one method may be used to produce weapons-grade material. After all, thermal, gas-diffusion, and EMIS techniques were all used to produce the highly enriched uranium for Little Boy, the bomb dropped on Hiroshima at the end of World War II.

For example, EMIS is particularly well-suited to further enriching uranium that has already been somewhat enriched, according to Thorne. Thus, although there is no proof that Iraq had such plans, centrifuges could have been used to enrich samples to, say, 12 percent U-235, and EMIS could have been used to bring them up to weapons-grade (93 percent).

A 'STARTLING FIND.' One of the most puzzling of the many mysteries surrounding the Iraq program is the possible discovery of weapons-grade uranium in a group of 25 samples taken inside the Tuwaitha complex. The samples, which were filter-paper smears taken off walls, floors, equipment, and other surfaces, were sent to several laboratories—one an IAEA laboratory at Seibersdorf, in Austria; the others U.S. facilities serving the intelligence community.

The Seibersdorf laboratory turned up no evidence of highly enriched uranium (HEU). But equipment at the U.S. laboratories, which is several orders of magnitude more sensitive than the Seibersdorf facility, found HEU—not only in the Tuwaitha samples, but in two control samples known to have *no* uranium isotopes at all. Repeated tests on additional samples gave the same results. Compounding the mystery, the U.S. laboratory said some of the uranium samples had a highly unusual isotopic composition, which

matched a common analytical standard used to test detection equipment. "On the face of it, it's a very startling find," Thorne said.

The Iraqis have steadfastly maintained that the places at Tuwaitha from which the samples were taken have never contained enriched uranium. "We've really hammered them on this one, and given them every face-saving opportunity to explain it," Thorne said. "But they've held to the story that they never had highly enriched uranium at that site." One current theory is that an HEU standard (analytical) sample somehow contaminated some of the Tuwaitha samples sent to the U.S. laboratory.

PUTTING IT ALL TOGETHER. Not limiting itself to producing weapons-grade materials (generally viewed as technologically the hardest task in building a bomb), Iraq was concurrently struggling to build a deliverable weapon around the material, a daunting task known as weaponization. Here, as in its enrichment efforts, Iraq took multiple approaches, mostly at a weapons-design and -testing complex not far from Al Atheer.

The two basic types of atomic bombs are gun devices and implosion weapons. The latter are much more difficult to design and build, but provide higher explosive yields for a given amount of fissile material. IAEA investigators have found no evidence that Iraq was actively pursuing a gun device; it is clear, they say, that they concentrated their money and resources on an implosion device, and had even started work on fairly advanced implosion designs.

In an implosion device, the fissile material is physically compressed by the force of a shock wave created with conventional explosives. Then, at just the right instant, neutrons are released, initiating the ultrafast fission chain reactions—an atomic blast. Thus the main elements of an implosion device are a firing system, an explosive assembly, and the core. The firing system includes vacuum-tube-based, high-energy discharge devices called krytrons that are capable of releasing enough energy to detonate the conventional explosive. The explosive assembly includes "lenses" that precisely focus the spherical, imploding shockwave on the fissile core, within which is a neutronic initiator. The IAEA has amassed ample evidence that the Iraqis had made progress in each of these areas.

Iraq's attempts to import krytrons from CSI Technologies Inc., San Marcos, Calif., made news in March 1990, when two Iraqis were arrested at London's Heathrow airport after an 18-month "sting" operation involving U.S. and British Customs. Several years before that failure, however, Iraq did manage to get weapons-quality capacitors from other U.S. concerns, and also produced its own capacitors. The latter, however, did "not seem to possess the characteristics necessary for storing the energy required by the multiple detonator system," the IAEA found.

Work on the conventional explosive assembly, which creates the collapsing shockwave, was carried out mainly at a large explosive production site near Al Qa Qaa. So far, IAEA investigators have found about 230 metric tons of a high-energy explosive, HMX, which is suitable for use in atomic bombs. The IAEA has not announced where the explosive came from, but a knowledgeable source told *Spectrum* it came from Czechoslovakia, where Iraq had bought large quantities of it for conventional military uses in its war with Iran.

The seventh IAEA inspection mission to Iraq found that two types of explosive lenses were fabricated and tested near Al Qa Qaa between March and May, 1990. Although both lenses were designed for planar shock waves, "it is prudent to assume that Iraqi scientists have a basic knowledge of the initiation of a spherical implosion," the inspectors wrote in their report on the mission.

The seventh mission also found that Iraqi scientists had used hydrodynamic computer programs to evaluate various core geometries. Also, facilities were found at Al Atheer that would have been suitable for large-scale uranium metallurgy, of the sort that would be necessary to produce the core of a bomb. Kay said he saw some evidence that at least preliminary tests had been carried out on the use of implosions to compress depleted (unenriched) uranium; such work would have enabled the Iraqis to study the symmetry and simultaneity of shock waves without risking a nuclear explosion.

> The Iraqis 'knew everything necessary to make a gun-assembly' atomic bomb

Indications are so far that Iraq was having trouble producing a neutronic initiator. Besides the usual polonium-beryllium design, several alternatives were being examined, none apparently with much success.

Among the more interesting documents found in Iraq is a proposal by an Iraqi Government chemist to produce tritium, the heaviest hydrogen isotope, by irradiating lithium-6. The disclosure of the document led to erroneous press reports that Iraq was at work on a thermonuclear (fusion) bomb. In all advanced atomic (fission) bomb designs, tritium is used in the core to boost the explosive yield, Thorne noted, and this may have been the use envisioned by the chemist.

In a gun-type atomic bomb, the chain reaction is initiated by hurling together in a tube, and with tremendous force, two samples of highly enriched uranium. Much more fissile material is needed than would be for an implosion weapon, and gun-type bombs are difficult, if not impossible, to deliver with a missile. But they can be quite effective, as Little Boy demonstrated. According to Kay, the Iraqis "knew everything necessary to make a gun-assembly device." He also said he found tungsten-carbide piping, which would be suitable for making the tube in which the samples would collide.

IGNORED CONSEQUENCES. Though Iraqi officials considered every angle and possibility in attempting to build an atomic bomb, they seem to have completely ignored the consequences of having one.

"I'm not sure the Iraqis had thought through the political and strategic implications of having a nuclear weapon," Kay said. "If the Israelis had known what the full size and scope of the Iraqi nuclear program was, I'm not sure what their reaction would have been when the Scuds started falling. I'm not sure that pressure from the United States and other countries would have been enough to keep the Israelis from reacting with massive force."

Unfortunately, such an outcome is still a possibility. Though the Iraqi nuclear program is now being dismantled, some analysts see parallels between the vanquished southwest Asian nation today and Germany after World War I. "While Iraq does not possess the industrial skills available to Germany in 1919, the full extent of Iraq's ability to infiltrate the economic structure of the West, particularly western Europe, in order to gain access to very high technology is just becoming known," wrote Geoffrey Kemp in *The Control of the Middle East Arms Race.*

"The danger is that once Iraq begins to export oil and gains access to hard currency, it will be able to hide a portion of its revenues for covert purposes," according to Kemp, a senior associate at the Carnegie Endowment for International Peace in Washington, D.C. "Once it has accumulated a sizeable hard currency account, it could once more use its financial resources to penetrate the arms market and buy the services of unemployed technicians and engineers in Europe, including East Europe and the Soviet Union."

TO PROBE FURTHER. *The Death Lobby: How the West Armed Iraq* is one of the most comprehensive accounts of its kind. Although it was written before the start of the inspection missions to Iraq, it has detailed histories of the country's procurement efforts and describes its methods and tactics. Written by Kenneth R. Timmerman, it was published by Houghton Mifflin, Boston, in 1991. *The Bulletin of the Atomic Scientists* has run several lengthy articles speculating on how advanced the Iraqi program was; see especially the March, July/August, and September 1991 issues. *The Control of the Middle East Arms Race,* by Geoffrey Kemp with Shelly A. Stahl, was published by the Carnegie Endowment for International Peace in Washington, D.C., last autumn. ◆

Part 2: Working to halt proliferation

Iraq showed the world how much a country might sacrifice—billions of dollars and millions of man-hours—for just a small nuclear weapons capacity.

Now there may be a shortcut. The breakup of the Soviet empire into poor, feuding states means the world's biggest nuclear arsenal and infrastructure could be accessible, at possibly bargain rates. As Zachary Davis of the U.S. Congressional Research Service, Washington, D.C., put it: "A solid member of the Nuclear Nonproliferation Treaty came undone and has turned into a potential source of proliferation."

The situation is a unique test case of the adequacy of the means of preventing the proliferation of nuclear weapons: seeing whether the huge nuclear resources of the former USSR can be contained with, among other things, reforms of existing monitoring regimes and a keener post-Iraq awareness of atomic mischief.

The fact that Iraq's huge effort remained hidden from the world's top intelligence agencies over many years, even during intense wartime scrutiny, does not augur well for uncovering, let alone preventing, other rogue efforts or any weapons-related smuggling along the vast ex-Soviet expanse.

Yet, for the first time since the Trinity explosion by Los Alamos scientists and engineers in 1945, nuclear arsenals—and the modernization of them—are being heavily pruned by mutual accords and unilateral pledges. Prospective nuclear weapons states like Brazil and Argentina are renouncing their military nuclear programs. But, as arsenals shrink, balancing military power becomes more delicate, so that the detection of cheating and embryonic nuclear forces becomes even more crucial, as does the monitoring of commercial nuclear power and fuel-reprocessing plants.

Finally, what to do with the energy-rich "waste" of plutonium and highly enriched uranium created by the massive disarming of the nuclear superpowers? Each side could destroy thousands of nuclear weapons a year into the next century, and decisions here may have great impact on future commercial nuclear power and on the proliferation of weaponry.

John A. Adam Senior Associate Editor

WHY WORRY? The leader of Russia's consolidation of some 27 000 nuclear weapons, Lieutenant General Sergei A. Zelentsov, told *IEEE Spectrum* on Feb. 27 that "accidents with nuclear warheads will arise" if the system erodes. This possibility, he said, was evident in light of recent riots of construction troops at the Baikonur Cosmodrome in Kazakhstan. Consequently, Russia is gathering in its far-flung tactical nuclear forces with an urgency that is taxing its secure transportation system.

The most imminent problem within the former Soviet Union involves the control of more than 15 000 tactical nuclear weapons—from mines and artillery shells to aircraft bombs and naval torpedoes. Compared with large strategic missiles, these are usually easy to transport and conceal, with some of the older devices lacking even permissive action links, meaning they could be activated without authorization.

> 'What we are trying to create is an early warning system across the board'

General Zelentsov said during a February news conference that all tactical nuclear weapons were already withdrawn from Central Asian, Baltic, and Caucasus states. Those remaining in Belorussia and Ukraine are being collected at a faster pace and could be moved to Russia by May, two months ahead of schedule, if the other republics comply.

Before being moved, the thousands of tactical nuclear weapons are disabled so they cannot produce as big a nuclear yield should an accident happen, although the variety and secrecy of tactical weapon design makes it difficult to generalize. Zelentsov implied that any weapons that can be irreversibly disabled in the field will be. Others will be stored deep inside Russia until the warheads can be dismantled and the fissile materials stored at one of two sites, Chelyabinsk or Tomsk.

Both U.S. and Russian experts said many media reports ignore the fact that the Soviet Union has had decades of experience in maintaining and guarding nuclear materials and weapons. General Zelentsov told *Spectrum* during an interview in Washington, D.C., that each nuclear weapon, including tactical ones, is accounted for, and its components are tracked from birth to retirement (when the fissile material has been usually recycled into new weapons). This contradicts the belief of some U.S. experts. Neither the United States nor the former Soviet Union has exchanged nuclear inventory data, so veracity is hard to check.

Although the Russians have technical personnel to disable and dismantle weaponry—largely the same people who used to build weapons—Zelentsov said help is needed to safely and securely transport the unprecedented flow of warheads. Railroad cars and armored vehicles in addition to cannisters are needed and cannot quickly be supplied by Russian industry because of the ailing economy.

Last November, the U.S. Congress authorized the redirection of up to US $400 million toward aiding the newly independent states in guarding their nuclear weapons, materials, and secrets. As of early March, the two sides had agreed to create a $25 million clearinghouse, through which former Soviet weapons designers may find other useful work within Russia while fostering openness with researchers in the West.

An "accounting system for nuclear material" is also to be devised, and 25 special rail cars designed to transport nuclear weapons are being sent from the United States—along with Kevlar blankets to protect cargo from small arms. (Gunfire could detonate the high-explosive trigger, probably touching off an asymmetric implosion that would disperse fissile material but not be large enough to start a chain reaction.)

Russian authorities are examining mass-producible U.S. containers for use in transporting and storing nuclear materials and components. Additionally, technical exchanges between U.S. and Russian experts

will examine responses to accidents involving nuclear weapons as well as short- and long-term methods of dealing with the plutonium and highly enriched uranium from weapons.

REASONS FOR FEAR. Because of the great demand for weapons-grade material, the difficulty in determining the authenticity of alleged nuclear materials, and the widespread availability of small amounts of fissile material in research reactors, threats will have to be taken more seriously. Robert M. Gates, director of the U.S. Central Intelligence Agency (CIA), Washington, D.C., predicted "many scams and hoaxes" as a result of the Soviet breakup, which "will make our job even more difficult."

As one European diplomat told *Spectrum*: "People have made a lot of money saying they are going to supply plutonium. They ask for $100 000, show a small sample, and then disappear. It's a terrific field for a confidence trickster."

The likelihood of hoaxes is hard to predict, though. Steven Dolly, research director of the Nuclear Control Institute, Washington, D.C., said, "Almost no one knows anything about the nuclear black market."

"If you look at what moves around the world in the drug trade, nothing in nuclear material makes it inherently harder to move," said David Kay, head of the Uranium Institute, London. Moving highly enriched uranium (HEU) is surprisingly easy and hard to detect since it has no volatility, unlike plutonium.

Smuggling in Central Asia and the Transcaucasus is an ancient and highly cultivated activity. Because the former Soviet republics border on states that are deeply interested in acquiring special weapons, "traders no doubt are acutely aware of the potential value of sensitive materials and technologies, and would be eager to act as middlemen," Gates told Congress in January. "Even when the KGB and the armed forces were controlling the borders in these areas, local communities conducted largely uncontrolled cross-border trade," he added. Now the borders are under local oversight, and some republics may become more closely aligned with other neighbors.

The CIA director said that inhibitions against trade in special weapons materials or equipment "may weaken and disappear."

While most of the nuclear infrastructure and all stations for dismantling weapons are in Russia, several nuclear power reactors and research reactors that could be used to enrich uranium or produce plutonium are located in Ukraine, Kazakhstan, Georgia, Uzbekistan, Belorussia, and Armenia, according to Amy Woolf, a Soviet specialist at the U.S. Congressional Research Service. She said a serious concern is exports from the uranium mines and mills in Central Asia, located in Kazakhstan and Uzbekistan.

But the "greatest concern," said Gates in assessing the sudden reduction of the Soviet nuclear weapons complex, is the potential brain drain, rather than the loss of weapons or material. It could mean a rogue state getting not just a nuclear product but an indigenous process.

Based on Soviet scientific and technical collaboration in the 1980s, Cuba, India, Syria, Egypt, and Algeria are most likely to have the contacts and resident scientists to assist Soviet emigrants, he said. He noted that experts need not cross borders in person. Faxes and computer modems are quick ways of transferring designs.

Asked about the migration of nuclear expertise, Boris V. Nikipelov, first deputy minister of the former Soviet Ministry of Atomic Power and Industry, Moscow, told *Spectrum*: "The majority of these scientists will go nowhere. But we have a Russian saying: 'There can always be a dwarf in the family.'"

Nikipelov, a former chief engineer at Chelyabinsk-70, one of two main weapons design laboratories, added it was "possible" that weapons designers loyal to Kazakhstan or Azerbaijan would leave the Russian labs, but he said there are no rumors that former Soviet states want nuclear devices.

According to the head of nuclear materials activity in the atomic ministry, however, migration is not much of a concern. There are restrictions regarding foreign travel, like those covering U.S. weapons scientists, Nikipelov said. The brain drain applies as well to Livermore and Los Alamos scientists who are faced with a similar lack of work, he added. Unlike Russian scientists, however, the U.S. scientists are accustomed to selling their wares in the marketplace.

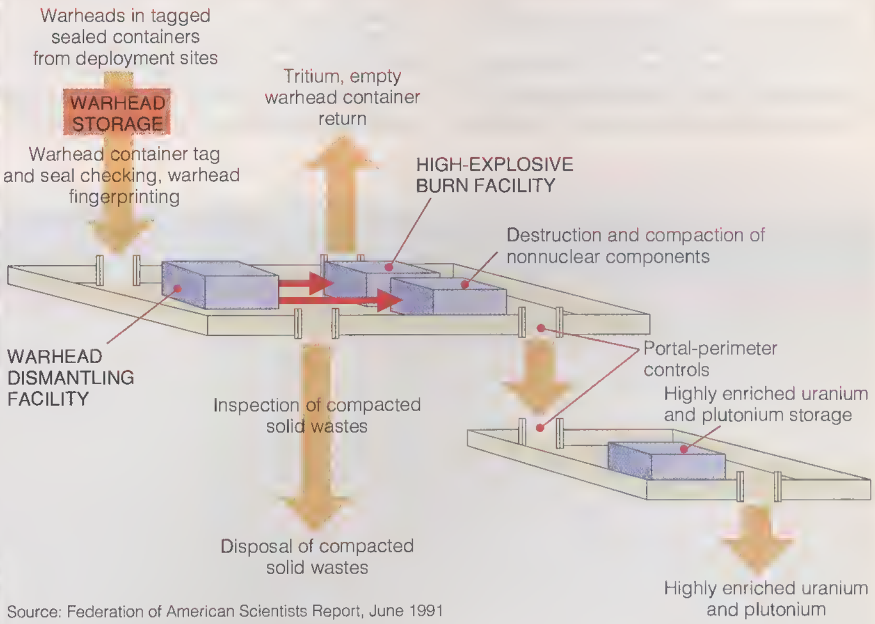
Evgeny Avrorin, scientific leader at the Institute of Technical Physics at Chelyabinsk, said the economy has left many experts jobless, but "I don't think we should exaggerate the gravity of the danger." The Russian added, "A great moral threshold has to be crossed. We are talking about highly skilled experts who realize what the consequences would be" not only for their country but for humankind.

CHETEK: NUKES FOR HIRE. An effort to privatize nuclear activities through an enterprise called Chetek is distressing to many U.S. experts. The Congressional Research Service's proliferation expert, Davis, calls them a "Mafia-like organization doing whatever they can to make money."

Chetek has close ties with a group from the ex-Soviet's Ministry of Atomic Power and Industry that has proposed using peaceful nuclear explosions as a means to destroy chemical weapons, chemical wastes, and nuclear weapons.

Yuri Trutnev, scientific leader at the Research Institute of Experimental Physics at the Arzamas-16 weapons laboratory, south of Gorkiy, estimates that one 50-kiloton blast can destroy the plutonium from some 5000 warheads. He offered as a rule of thumb that each kilogram of plutonium would be diluted on average by one kiloton of melted vitrified rock. The laboratory conducted two underground explosions for experimental data on leaching from the blast area—both proved reassuring, said Trutnev, a Chetek associate. But questions remain on how much plutonium would not be vitrified and how sta-

Safeguards at a nuclear-warhead dismantling facility



Source: Federation of American Scientists Report, June 1991

This concept for monitoring a facility for dismantling nuclear warheads would allow the host country privacy for its sensitive weapon designs. Inspection by another party at perimeters and portals would verify incoming warheads and outgoing fissile material destined for another safeguarded facility for storage.

ble geologic conditions at the sites would be.

Vadim A. Simonenko and a few colleagues at the Chelyabinsk laboratory noted in a recent paper that from 1977 to 1988 more than 60 peaceful nuclear explosions were carried out in the Soviet Union to cap oil and gas gushers, create underground storage cavities, and facilitate extraction of ore and oil. The implication was that such technology and experience should not be wasted.

DISMANTLE AND DEPOSIT. Any international monitoring of Soviet or U.S. withdrawals has so far been precluded by the urgency of the "loose nukes" situation and traditional sensitivities. "This is not arms control," observed Soviet specialist Woolf. "This is weapons control and technical assistance."

A Senate staff member, well versed in the technology of verification, said there is not too much incentive yet to cheat. But he added that "maybe by the year 2000 when we have 2000 weapons and controlled plutonium stocks, we'll be very sorry we didn't do better bookkeeping in 1992."

Russia, under General Zelentsov's direction, has abruptly dismissed suggestions by the Natural Resources Defense Council Inc., Washington, D. C., that warheads in the field be tagged with unique signatures for inventory control. But Zelentsov's group seems amenable to bilateral or multilateral monitoring of the fissile material from dismantled warheads. Zelentsov said this will reassure affected local communities and convince the world that disarmament is taking place [on p. 67 appears a schematic by private U.S. researchers showing a possible monitoring setup using such things as simple optical-fiber cable locks as seals and gamma-ray or neutron detectors to assay fissile material].

The United States would like Russian warheads dismantled as fast as possible, within the bounds of safety and security, to make rearmament more difficult. Deputy minister Nikipelov told *Spectrum* of a big reserve in dismantling capabilities allowing Russia to take apart 2500–3000 warheads a year, provided there is adequate storage. (The CIA views this assessment as extremely optimistic.)

Russia has also been seeking all the money authorized by Congress for a storage facility. But a $400 million price tag is considered too high by many U.S. experts, particularly in the absence of detailed plans.

Those plans could be ready by year-end, Nikipelov told *Spectrum*. Currently they envision one or two facilities to hold 100 metric tons of plutonium and perhaps 500 metric tons of highly enriched uranium from all dismantled tactical and strategic weapons and previously stockpiled material. Questions remain on the fissile materials' ultimate resting place and thus on how temporary or permanent to make the storage.

WASTE NOT. Longer-term anti-proliferation measures include finding ways to turn the stockpiled nuclear materials into useful civilian products. The idea of irreversibly converting bomb material into fuel for reactors is an alluring one. Then weapons-grade elements would require only temporary storage. The plutonium and uranium in weapons afford more energy than the same elements used as reactor fuel.

The least controversial is converting highly enriched uranium (HEU). About 30 metric tons of HEU, which might be extracted annually from weaponry in the United States and Russia, equals some 7000 metric tons of natural uranium and some 4300 metric

Nations and nuclear weapons

Country	Current status	Party to Nonproliferation Treaty (NPT)	Open to inspection	Comments
Nations having *de jure* nuclear weapons				
Russia	Is consolidating some 27 000 strategic and tactical nuclear weapons from former USSR, including 9537 strategic weapons[a]	Yes	Are viewed as nuclear-weapon states under NPT whether or not signatories to it, so are not subject to safeguard inspections by IAEA; have volunteered some or all of their civil nuclear facilities for inspection by IAEA, which, however, has looked into the peaceful use of only a few	Still has a more secretive military infrastructure than the United States; is eliminating some 15 000 tactical weapons, reducing nuclear arms complex at slower pace than in the United States, cutting strategic weapons in half under Start agreement with United States, and seeking cuts to some 3000 strategic warheads and eventual total ban
United States	Has about 20 000 nuclear warheads (8772 strategic); banned its intermediate-range nuclear missiles under 1987 U.S.-Soviet INF accord; announced the unilateral withdrawal of all its tactical nuclear weapons (about 7100 devices) in 9/91	Yes		Seeks eventual strategic cuts beyond Start, but not as extensive as those put forth by Russia; is reducing nuclear arms complex (fate of weapons plutonium and highly enriched uranium from dismantling is undetermined)
France	Has approximately 436 strategic nuclear weapons	No[b]		Seeks to maintain nuclear status, but after relatively poor showing in Gulf War, not at the expense of conventional forces
United Kingdom	Has approximately 96 strategic nuclear weapons	Yes		Seeks to maintain nuclear status and close cooperation with U.S. nuclear establishment
China	Has approximately 324 strategic nuclear weapons	Yes (3/92)		With its signing of the NPT, has to require all importers of its nuclear equipment to adhere to IAEA safeguards
***De facto* nuclear weapons nations**				
India	Has essentials for 75–100 atomic bombs and large stocks of plutonium	No	Specific nuclear facilities, power reactors, and research reactors are under limited IAEA safeguards	Is unwilling to sign NPT, even if Pakistan does, because of China threat; has recently greatly expanded nuclear weapons production capability; is reportedly designing H-bomb; has held no further bomb tests after single event in 1974; since 1989 has tested nuclear-capable missiles with up to 2400-km range
Pakistan	May have material and components for 15–20 undeclared A-bombs; foreign secretary recently admitted country's nuclear status, possibly gained in 1986 with China's help	No		Has stated it will sign NPT if India does; CIA said the United States remains opposed to exports of space launch vehicle or advanced computer technology to both India and Pakistan because of "high probability" of use in nuclear long-range ballistic-missile program
Israel	Probably has at least 75 weapons, including low-blast, high-radiation "neutron bombs," from effort since 1960s	No		Is suspected of having plutonium and possible HEU facilities; possibly conducted tests in South Atlantic in 1979 with South Africa; has been testing intermediate-range missile since 1987; shows no sign of curbing nuclear program
Nations actively seeking nuclear weapons				
Iraq	Had multitrack program [see pp. 20–24 and 63–65]	Yes	Despite inspections, hid extensive weapons effort; after Gulf War was found to have violated NPT by secretly making nuclear materials	Most facilities found and dismantled during or after 1991 Gulf War; United Nations sanctions and tougher export policies may delay effort to make device

tons of separative-work units of enrichment services. Reducing the amounts of undesirable isotopes such as alpha emitter U-234 is important for practical commercial handling, but how to introduce the HEU without flooding the sensitive world markets in uranium and uranium enrichment seems to be the main concern of both military superpowers. (The composition of HEU is not public knowledge, so exactly which isotopes need to be neutralized is not clear.)

Taking into account just the cost of the inefficient gaseous diffusion method of enrichment typical in the United States, Thomas Neff, a member of the center for international studies at the Massachusetts Institute of Technology (MIT), Cambridge, estimates the value of 1 kilogram of HEU at about $10 000, or worth its weight in gold.

What to do with military plutonium is much more of a problem, one that also relates to commercial nuclear power issues. As a waste product of commercial reactors, plutonium is mixed with other elements and cannot readily be used for power or weaponry. But once this waste is chemically reprocessed, the plutonium produced each year in a gigawatt reactor could produce enough fissile material for 25 nuclear warheads, according to a 1988 paper by David Albright and Harold A. Feiveson in *Annual Reviews of Energy*. Unlike commercial uranium fuel, all isotopes of plutonium are readily fissionable and thus can be used in bombmaking.

A typical commercial power reactor produces some 30 tons of spent fuel a year. By the year 2000, France, Great Britain, Germany, and Japan (all densely populated countries that emphasize nuclear power programs) expect to be separating some 27 metric tons of plutonium per year from spent fuel. The plutonium would go to facilities for blending with uranium into mixed-oxide fuel elements.

Those concerned with proliferation worry about the shipments being intercepted and civilian programs becoming easier to convert to weapons production. Feiveson, a professor at Princeton University in New Jersey, noted that shipments of reprocessed plutonium from Europe to Japan are expected to begin soon and may have enough material for perhaps 100 bombs.

Nikipelov, the former Chelyabinsk nuclear engineer, personally believes the military plutonium should be used for power—in new fast nuclear reactors using mixed uranium and plutonium fuel. A test reactor is under construction at Chelyabinsk, and Russia is already experimenting with plutonium-burning fast-neutron reactors.

MISSING 250 KILOS OF PLUTONIUM? Strict inventories on U.S. and Russian storage sites are only a part of a program to ensure nondiversion. There are indications, besides the Iraq case, that show some current safeguards are dangerously lax.

The International Atomic Energy Agency (IAEA), the world monitor for the nuclear nonproliferation treaty (NPT) based in Vienna, Austria, uses "significant quantity" guidelines derived in 1977 to drive its safeguards program. Thus, 8 kg of plutonium, 25 kg of HEU, and 75 kg of low-enriched uranium are each thought to be enough to create a nuclear bomb.

Assuming diversion of the uranium or plutonium to military ends was successful, its conversion to components of an explosive device was estimated by an advisory group at 7–10 days for metallic plutonium and

Country	Current status	Party to Nonproliferation Treaty (NPT)	Open to inspection	Comments
Iran	Acquiring small neutron source reactor from China and electromagnetic isotope separator—dual-use capabilities	Yes	Full-scope safeguard agreement in force	Is actively seeking nuclear weapons, with research believed ongoing at secret facilities; is clandestinely seeking technology in Western Europe
Libya	Failed in attempts to buy atomic bomb in early 1970s and in 1981; seems as yet to have no major nuclear weapons facilities under construction	Yes		Is still seeking weapons of mass destruction, despite international ostracism by former clients like China and Russia, as well as others
North Korea	Is a significant military exporter; has indigenous nuclear infrastructure, from uranium mines to reprocessing of reactor fuel; will soon have two nuclear reactors for making plutonium	Yes	Recently signed safeguard agreement, though it is not yet in force; two research reactors under limited IAEA safeguards	Signed recent pact with South Korea to create nuclear weapons-free peninsula and to forbid reprocessing or enrichment facilities; verification remains to be worked out
Nations possibly interested in nuclear weapons				
Algeria	Has nearly finished a second nuclear reactor begun secretly in 1986 with Chinese assistance and said to be for civilian purposes	No	Two research reactors under limited IAEA safeguards as of 2/92	New reactor to be under IAEA safeguards because of international pressure after its early 1991 "discovery"; reactor is for research but could make weapons material; CIA is concerned about the secrecy of original agreement
Syria	Is negotiating with China for nuclear reactor, though no nuclear capability at present	Yes	Safeguard agreement signed but not in force; no significant nuclear activity until now	Appears to be seeking help from China and Western firms for an improved capability using chemical and biological warheads
Nations abandoning *de facto* nuclear weapons program				
Argentina	Has facilities necessary for nuclear weapons capability as part of nuclear energy program	No	Argentina and Brazil signed a December 1991 agreement, not yet in force, creating a joint safeguard authority whose inspections will be paralleled by IAEA inspections; IAEA currently inspects both nations under limited agreements (Infcirc 66)	Dropped its Condor II missile program in 1991, a project with Egypt and Iraq for a short-range missile with nuclear capability; civilian government opposes nuclear arming
Brazil	Civilian government recently halted nuclear weapons program launched in 1979	No		Is doing some work on short-range missiles with nuclear capabilities and is building space launch vehicle with long-range missile potential; has placed space launch program under civilian control
South Africa	Is assumed to have essentials for 15–25 devices from decade-long effort	Yes	Full-scope safeguards recently in force	IAEA conducting initial inventory of all declared nuclear materials
Taiwan	Has sizeable nuclear power program but lacks facilities to produce material for nuclear weapons; dismantled secret lab to extract plutonium in 1987 under U.S. pressure (similar attempt also thwarted by United States in mid-1970s)	Yes	Legal status of Taiwan is controversial (it is not a state from U.N. perspective); safeguard agreements concluded are not full-scope, only specific-facility	—

Sources: Carnegie Endowment for International Peace, Center for Strategic and International Studies, Federation of American Scientists, and Natural Resources Defense Council Inc., all in Washington, D.C.; U.S. Central Intelligence Agency testimony; International Atomic Energy Agency, Vienna; International Institute of Strategic Studies, London; Jaffee Center for Strategic Studies, Tel Aviv; *IEEE Spectrum* interviews

CIA = Central Intelligence Agency; HEU = highly enriched uranium; IAEA = International Atomic Energy Agency; INF = intermediate-range nuclear forces; Infcirc = information circular; NPT = Nonproliferation Treaty; Start = Strategic Arms Reduction Talks.

a Of these, 1400 are in newly independent Kazakhstan, which at press time it is hoped will agree in late March to sign the Start treaty. Start covers 1040 on ICBMs; 360 at a bomber base are a gray area.
b Although not yet a signatory, France has stated its intent to become one and has acted as if it is already one with regard to nuclear exports.

HEU; 7–21 days for pure unirradiated compounds of these mixtures such as oxides or nitrates; 1–3 months for plutonium or HEU in irradiated fuel; and one year for low-enriched uranium.

The time the international community takes to detect that material is missing, of course, should be shorter than the conversion time. The guidelines indicate, though, why proliferation experts fear the use of plutonium in the commercial fuel cycle.

Unfortunately, the IAEA safeguard detection goals cannot be met at large reprocessing and plutonium fuel fabrication facilities using conventional materials accountancy, according to Marvin M. Miller of MIT's department of nuclear engineering. For example, with the current state of the art in measurement technology, the minimum amount of plutonium that can be detected with high confidence from a large, spent-fuel reprocessing plant is on the order of 250 kg per year, Miller told *Spectrum*. In other words, each year about 30 significant quantities of bomb material could be skimmed off.

Near real-time accountancy is a possible solution—for instance, weekly rather than yearly inventory measurements that can be done without shutting a plant down. Cost and intrusiveness have yet to be assessed. But MIT's Miller concludes in a 1990 Nuclear Control Institute paper that until these measures can be implemented and demonstrated, "it would be prudent to limit plutonium use to research, development, and demonstration projects."

With the current glut of uranium, to be augmented by the U.S. and ex-Soviet weapons material, the world can take time to investigate the feasibility of reactors, including breeders, which are not only safer and make waste disposal more tractable, but also have a higher degree of proliferation and terrorist "resistance" than the standard breeder and its associated fuel cycle, Miller said. He added, "If nuclear power is to have a future, it should be in this direction."

INTELLIGENCE WOES. Other monitoring failings surfaced during a Senate hearing in January, when the top intelligence officials in the United States were repeatedly humbled by queries. "I simply don't know much," said Gordon Oehler, the CIA's National Intelligence Officer for Science, Technology, and Proliferation, when asked about Cuba's alleged interest in acquiring nuclear weapons and material. How about a reported uranium shipment from Iraq to Algeria? "I know nothing about it," he said. Gates responded, "We'll check."

In general, Gates said, "advances in special weapons are extraordinarily difficult to monitor." The solution, he said, is adding more spies rather than more technical surveillance.

Others do not completely agree. The Uranium Institute's Kay, who is a former IAEA inspector detained in that parking lot in Iraq, told *Spectrum* of the need for on-site analysis of particles indicative of nuclear malfeasance. He had to wait months before an Iraqi sample of particles that might have indicated illicit activity was analyzed in U.S. laboratories.

Department of Energy (DOE) laboratory experts say the possibilities include real-time seals and remote sensing to detect fissile materials and biological and chemical activity. Given, say, $10 million, the trend is to go from zero to 20 percent in new verification capabilities rather than from 90 to 95 percent in traditional means, said Anthony F. Czajkowski, acting director of the DOE office of arms control and nonproliferation. The new remote sensing tools might also be useful for assaying environmental cleanups.

POST-IRAQ REFORMS. Of all the controls on weapons of mass destruction and ballistic missiles, those for safeguarding nuclear capabilities are the strictest. The uncovering of Iraq's secret nuclear weapons program after the Gulf War was therefore a real eye-opener for the IAEA and other international bodies for monitoring and control.

Iraq imported critical equipment and components by exploiting loopholes in the global nuclear export system. IAEA inspections under the NPT failed to uncover any signs of Iraq's nuclear weapons program, nor did they detect misuse of a research reactor that was subject to safeguards.

IAEA spokesman David Kyd said that after the war, "what we are trying to create is an early warning system across the board," looking at the design of facilities and patterns of trade, rather than only later stages of the nuclear fuel-cycle.

The postwar license to monitor Iraq is exceptional because the agency had access to satellite imagery and defectors, and had international support against a defeated aggressor, so that intrusive inspection was possible. Even so, inspectors still have not found the headquarters of the Iraqis' centrifuge program or the supplier network, to name two forbidden activities.

Usually the IAEA inspectors receive no intelligence data and visit only the declared facilities of member states. In Iraq and elsewhere, the agency had never conducted surprise inspections. Some have charged that inspections are perfunctory. Kay told *Spectrum*, "If you put [some nuclear material] in front of them, they will count every grain" but not bother to inquire about any suspected malfeasance.

In February, the IAEA board of governors, from 35 countries, reaffirmed the agency's right to descend on undeclared facilities with special inspections on the basis of intelligence information. The governors also will require member states to submit preliminary designs of nuclear facilities as soon as a decision is made to build them. The idea is to influence designs to make them easier for IAEA to inspect thoroughly.

Action on a proposal for the import and export of nuclear material and sensitive nonnuclear equipment was deferred until the next meeting in June, when a draft protocol can be presented. IAEA spokesman Kyd said such data would be valuable to construct a pattern of imports.

For example, Iraq imported 240 000 ferrite magnets. Such a huge amount might have aroused suspicion, he said. The magnets were used for 10 000 centrifuges, which separate weapons-grade uranium from less fissile isotopes. Yet, for some countries like Belgium, Canada, and Japan, such openness to inspection may be unduly burdensome to enact, and they are not convinced of its effectiveness.

The IAEA itself is "overburdened and understaffed" and suffers from "severe political, technological, and budgetary shortcomings," said Paul L. Leventhal, president of the Nuclear Control Institute. Few disagree, even within the agency. The IAEA's 211 inspectors must apply safeguards to nearly 1000 installations, making some 2200 inspections a year with a budget of $60 million.

The amount of fissionable material under IAEA safeguards rose about 10 percent a year in the late 1980s and could soar if the agency monitors the weapons-material inventory of the former Soviet Union, as it has proposed. Among nonnuclear weapons states, some 95 percent of all fissionable material and the same percentage of nuclear installations are under safeguards [see table, this page].

Suggested improvements to the nonproliferation treaty, up for renewal in 1995, include: making certain processes and materials illegal (rather than just the end product of a nuclear device); requiring NPT states to export nuclear technology only to those nations whose entire nuclear program (not just a particular facility) is placed under safeguards; and improving enforcement by

What IAEA safeguards

Installations: total = 515	
Power reactors	183
Research reactors and critical assemblies	173
Uranium chemical-conversion plants	8
Fuel fabrication plants	43
Enrichment plants (including pilot plants)	7
Reprocessing plants (including pilot plants)	5
Separate storage facilities	45
Other facilities (mostly laboratories)	51
Materials, metric tons	
Plutonium in irradiated fuel	284.8
separated	13.6
recycled, in fuel elements in reactor cores	1.1
Uranium, highly enriched(>20% U-235)	10.8
low-enriched	33 833
Uranium or thorium, natural or depleted	57 134

Source: International Atomic Energy Agency, *Annual Report for 1989*

the IAEA safeguards regime, according to Leventhal.

Davis, the nonproliferation expert at the U.S. Congressional Research Service, warned of the diminishing returns to be obtained from increasing surveillance of declared nuclear facilities. Covert programs or projects in countries that have not signed the NPT is where most action is, which means supplier controls must be more stringent. This is mainly outside the IAEA's reach but within the purview of the Nuclear Suppliers Group.

Since the Gulf War, the work done in developing new guidelines on export controls by this group of 27 nations has ended a decade of inactivity. A meeting in early April in Warsaw could yield the first multilateral approach on dual-use items for nuclear weapons. The proposed control list and basic guidelines are modeled on an existing U.S. export control system. If approved, it would control not only fuel-cycle elements but such equipment as electronics to ignite bombs and high-speed cameras for nuclear testing, according to a U.S. administration official. Enforcement mechanisms are not yet addressed.

The so called Zangger Trigger List of 1974, with 23 NPT exporters as constituents, is also being updated to tighten upgrades for reprocessing and enrichment.

"Things are moving in the right direction," Davis said. Although India and Pakistan are not parties to the NPT and can legally sell what they have to whomever they want, India recently canceled plans to sell reactors to Iran under U.S. diplomatic pressure.

GROWING NUCLEAR TABOO? With big cuts in the post-Cold War arsenals, a goal might be to reduce to an absolute minimum the role of nuclear weapons and to "bring about a global nuclear taboo," said Lewis A. Dunn, who was U.S. ambassador to the 1985 NPT Review Conference.

Already more than 140 countries have renounced the right to acquire weapons under the NPT, "an obligation that is taken seriously by virtually all of them," Dunn stated in a recent study for the International Institute for Strategic Studies, London. The treaty also remains an important counterweight to any future nuclear second thoughts on the part of Germany, the countries of Eastern Europe, and Japan.

The Gulf War highlighted well-known intelligence shortfalls in finding mobile missiles and an entire covert nuclear weapons program. It also might have shown some rogue states that only nuclear weapons will deter modern conventional force. But the nascent role of antimissile technology and conventional weaponry demonstrated in the war may also help convince rogue states that a painstaking covert program to produce a small number of nuclear weapons may be of diminishing utility.

Whatever the reasons, a number of key nations, from China to South Africa, have recently decided to sign the NPT. Several countries are still viewed as wanting to acquire the weapons [see table, pp. 68–69]. Kyd of the IAEA said there are now only four significant countries outside the NPT: India, Pakistan, Israel, and Algeria.

Without improvements, however, the Nuclear Control Institute's Leventhal cautions against automatic extension of the treaty in 1995, saying that the treaty has facilitated the spread of nuclear weapons. A country may join only because participation is conditional to getting "peaceful" nuclear technology.

Plutonium for 30 bombs can be skimmed each year without detection from a large commercial reprocessing plant

Relatively few people are talking about some kind of technical renaissance in the post-Cold War era. Yet greater cooperation between some of the world's best engineers and scientists in the East and West might stem proliferation, help spur research into safer nuclear reactors, and facilitate waste disposal and cleanup—and at the same time mitigate Russian brain drain concerns.

In March, a group at the National Academies of Science and Engineering, Washington, D.C., urged the U.S. government to act "immediately and aggressively" to help reorient the military R&D effort of the former Soviet Union and develop the civilian component. Among the recommendations were to use funds from the $400 million for immediate support of new research opportunities, including $25 million for cooperative programs for non-weapon scientists, and to create a special fund of $50–$100 million to replenish equipment, journals, and books used in the former Soviet laboratories of special importance. The group also called on the Government to modify policies concerning the acquisition by U.S. firms of advanced technologies and technical expertise from the former Soviet Union.

The DOE's Czajkowski noted that Russians are "technically very competent and proud" and their laboratories might contribute to gains in such global areas as energy and the environment. He added that there are areas where Soviets are ahead and where it might be cheaper for the United States to contract research.

Robert Galucci, a U.S. State Department official, said it is hoped that the new clearinghouse center will encourage a mixing of Soviet military and civilian scientists with U.S. experts, with an aim toward keeping skilled expertise in Russia. He added that retraining or language instruction might be part of the deal.

"The only thing we are lacking is financing," said Trutnev, who ticked off potential areas from diagnostics to diamond production using chemical explosives. Researchers at Chelyabinsk-70, including Evgeni N. Avrorin, advocate an international effort to use nuclear explosions to advance science in such areas as inertial confinement fusion, high-intensity magnetic fields, and the study of matter under extreme conditions.

Chelyabinsk's Vadim A. Simonenko is also forming a group within the Institute of Technical Physics to work on future computer technologies and said he can marshal more than 400 persons to develop algorithms and application software. Avrorin and others at Chelyabinsk propose that the former nuclear weapons test center at Semipalatinsk, Kazahkstan, be turned into an international facility to test and raise the safety of nuclear reactors.

Private U.S. groups will soon set up small-scale electronic mail nodes at the two leading Russian labs to show the viability of increased contact. Mission-oriented government laboratories, it was remarked at a recent Federation of American Scientists workshop attended by Russian leaders, need missions other than designing doomsday machines.

TO PROBE FURTHER. Many relevant reports exist. One is "Ending the production of fissile materials for weapons: Verifying the dismantlement of nuclear warheads," Federation of American Scientists, Washington, D.C., June 1991. Another is "Verified Storage and Destruction of Nuclear Warheads," Natural Resources Defense Council, Washington, D.C., December 1991.

The U.S. Library of Congress published "Nuclear Weapons in the Former Soviet Union" and "Nuclear Scientists of the Former Soviet Union: Nonproliferation Issues," through its Congressional Research Service, 1992.

In August 1991, "The Future of the U.S.-Soviet Nuclear Relationship," was printed by the National Academy of Sciences, Washington, D.C. Additional reports are "Limiting and Reducing Inventories of Fissionable Weapons Materials," by L. Charles Hebel, Center for International Security and Arms Control, Stanford University, Stanford, Calif., November 1991, and "Containing Nuclear Proliferation," Adelphi Papers, 263, International Institute for Strategic Studies, London and Washington, D.C.

Arms Control Today, Washington, D.C., put out a special issue on "Nuclear Weapons in the Former Soviet Union," January/February 1992. The Nuclear Control Institute, also in Washington, D.C., has published many concise papers by various experts, among them "Latent and Blatant Proliferation: Does the NPT Work Against Either?," August 1990. ◆

Claude E. Shannon

His colleagues label him inventor, tinkerer, puzzle-solver, prankster, and the father of information theory

Who is the real Claude Shannon? A visitor to Entropy House, the stuccoed mansion outside Boston where Shannon and his wife Betty have lived for more than 30 years, might reach different conclusions in different rooms. One room, prim and tidy, is lined with plaques that solemnly testify to Shannon's numerous honors, including the National Medal of Science, which he received in 1966; the Kyoto Prize, Japan's equivalent of the Nobel; and the IEEE Medal of Honor.

That room enshrines the Shannon whose work Robert Lucky, the executive director of research for AT&T Bell Laboratories, has called the greatest "in the annals of technological thought," and whose "pioneering insight" IBM Fellow Rolf W. Landauer has equated with Einstein's. That Shannon is the one who, as a young engineer at Bell Laboratories in 1948, defined the field of information theory. With a brilliant paper in the *Bell System Technical Journal*, he established the intellectual framework for the efficient packaging and transmission of electronic data. The paper, entitled "The Mathematical Theory of Communication," still stands as the Magna Carta of the communications age.

But showing a recent visitor his awards, Shannon, who at 75 has a shock of snowy hair and an elfish grin, seemed almost embarrassed. After a fidgety minute, he bolted into the room next door. This room has framed certificates, too, including one certifying Shannon as a "doctor of juggling." But it is also lined with tables heaped with all kinds of gadgets.

Some of these treasures—such as the talking chess-playing machine, the hundred-bladed jack-knife, the motorized pogo-stick, and the countless musical instruments—Shannon has collected through the years. Others he has built himself: a miniature stage with three juggling clowns, a mechanical mouse that finds its way out of a maze, a juggling mannikin of the comedian W. C. Fields, and a computer called Throbac (Thrifty Roman Numeral Backward Computer) that calculates in Roman numerals. Shannon tried to get the mannikin W. C. Fields to demonstrate his prowess, but in vain. "I love building machines, but it's hard keeping them in repair," he said a bit wistfully.

John Horgan

This roomful of gadgets reveals the other Shannon, the one who rode through the halls of Bell Laboratories on a unicycle while simultaneously juggling four balls, invented a rocket-powered frisbee, and designed a "mind-reading" machine.

This room typifies the Shannon who—seeking insights that could lead to a chess-playing machine—began playing so much chess at work that "at least one supervisor became somewhat worried," according to a former colleague.

Shannon makes no apologies. "I've always pursued my interests without much regard for financial value or value to the world," he said cheerfully. "I've spent lots of time on totally useless things."

THE GOLD BUG INFLUENCE. Shannon's delight in both mathematical abstractions and gadgetry emerged early on. Growing up in Gaylord, Mich., near where he was born in 1916, Shannon played with radio kits and erector sets supplied by his father, a probate judge. He also enjoyed solving mathematical puzzles given to him by his sister, Catherine, who eventually became a professor of mathematics.

> Shannon's treasures include a hundred-bladed jack-knife and a motorized pogo-stick

"I was always interested, even as a boy, in cryptography and things of that sort," Shannon said. One of his favorite stories was "The Gold Bug," an Edgar Allan Poe mystery with a rare happy ending: by decoding a mysterious map, the hero finds a buried treasure.

As an undergraduate at the University of Michigan in Ann Arbor, Shannon majored in both mathematics and electrical engineering. His familiarity with the two fields helped him notch his first big success as a graduate student at the Massachusetts Institute of Technology (MIT) in Cambridge. Following a discussion of complex telephone switching circuits with Amos Joel, famed Bell Laboratories expert in the topic, in his master's thesis Shannon showed how an algebra invented by the British mathematician George Boole in the mid-1800s—which deals with such concepts as "if X or Y happens but not Z, then Q results"—could represent the workings of switches and relays in electronic circuits.

The implications of the paper by the 22-year-old student were profound: circuit designs could be tested mathematically, before they were built, rather than through tedious trial and error. Engineers now routinely design computer hardware and software, telephone networks, and other complex systems with the aid of Boolean algebra.

Shannon's paper has been called "possibly the most important master's thesis in the century," but Shannon, typically, downplays it. "It just happened that no one else was familiar with both those fields at the same time," he said. After a moment's reflection, he added, "I've always loved that word, 'Boolean.' "

Receiving his doctorate from MIT in 1940 (his Ph.D. thesis addressed the mathematics of genetic transmission), Shannon then spent a year at the Institute for Advanced Study in Princeton, N.J. Lowering his voice dramatically, Shannon recalled how he was giving a talk at the institute when suddenly the legendary Einstein entered a door at the rear of the room. Einstein looked at Shannon, whispered something to another scientist, and departed. After his talk, Shannon rushed over to the scientist and asked him what Einstein had said. The scientist gravely told him that the great physicist had "wanted to know where the tea was," Shannon said, and burst into laughter.

HOW DO YOU SPELL 'EUREKA'? Shannon went to Bell Laboratories in 1941 and remained there for 15 years. During World War II, he was part of a group that developed digital encryption systems, including one that Churchill and Roosevelt used for transoceanic conferences.

It was this work, Shannon said, that led him to develop his theory of communication.

0018-9235/92/$3.00©1992 IEEE

Stanley Rowin

Vital statistics

Name: Claude Elwood Shannon
Date of birth: April 30, 1916
Place of birth: Petosky, Mich.
Height: 178 cm
Weight: 68 kg
Childhood hero: Thomas Alva Edison
First job: Western Union messenger boy
Family: married to Mary Elizabeth (Betty) Moore; three children: Robert J., computer engineer; Andrew M., musician; and Margarita C., geologist
Education: B.S., 1936, University of Michigan; M.S., 1940, Ph.D., 1940, Massachusetts Institute of Technology
Hobbies: building gadgets, juggling, unicycling
Favorite invention: a juggling W. C. Fields robot
Favorite author: T. S. Eliot
Favorite music: Dixieland jazz
Favorite food: vanilla ice cream with chocolate sauce
Memberships and awards: Fellow, IEEE; member, National Academy of Sciences, American Academy of Arts and Sciences; 1966 IEEE Medal of Honor; 1966 National Medal of Science; 1972 Harvey Prize; 1985 Kyoto Prize
Favorite award: 1940 American Institute of Electrical Engineers award for master's thesis

He realized that, just as digital codes could protect information from prying eyes, so could they shield it from the ravages of static or other forms of interference. The codes could also be used to package information more efficiently, so that more of it could be carried over a given channel.

"My first thinking about [information theory]," Shannon said, "was how you best improve information transmission over a noisy channel. This was a specific problem, where you're thinking about a telegraph system or a telephone system. But when you get to thinking about that, you begin to generalize in your head about all these broader applications." Asked whether at any point he had a "Eureka!"-style flash of insight, Shannon deflected the simplistic question with: "I would have, but I didn't know how to spell the word."

The definition of information set forth in Shannon's 1948 paper is crucial to his theory of communication. Sidestepping questions about meaning (which he has stressed that his theory "can't and wasn't intended to address"), Shannon demonstrated that information is a measurable commodity. The amount of information in a given message, he showed, is determined by the probability that—out of all the messages that could be sent—that particular message would be selected.

He defined the overall potential for information in a system as its "entropy," which in thermodynamics denotes the randomness—or "shuffledness," as one physicist has put it—of a system. (The great mathematician and computer theoretician John von Neumann persuaded Shannon to use the word entropy. The fact that no one knows what entropy really is, von Neumann argued, would give Shannon an edge in debates over information theory.)

Shannon defined the basic unit of information, which John Tukey of Bell Laboratories dubbed a binary unit and then a bit, as a message representing one of two states. One could encode a great deal of information in relatively few bits, just as in the old game "Twenty Questions" one could quickly zero in on a correct answer through deft questioning.

Building on this mathematical foundation, Shannon then showed that any given communications channel has a maximum capacity for reliably transmitting information. Actually, he showed that although one can approach this maximum through clever coding, one can never quite reach it. The maximum has come to be known as the Shannon limit.

Shannon's 1948 paper showed how to calculate the Shannon limit—but not how to approach it. Shannon and others took up that challenge later. The first step was to eliminate redundancy from the message. Just as a laconic Romeo can get his message across with a mere "i lv u," a good code first compresses information to its most efficient form.

A so-called error-correction code then adds just enough redundancy to ensure that the stripped-down message is not obscured by noise. For example, an error-correction code processing a stream of numbers might add a polynomial equation on whose graph the numbers all fall. The decoder on the receiving end knows that any numbers diverging from the graph have been altered in transmission.

Aaron D. Wyner, the head of the Communications Analysis Research Department at AT&T Bell Laboratories, Murray Hill, noted that some scientific discoveries seem in retrospect to be inevitably products of their times—but not Shannon's.

In fact Shannon's ideas were almost too prescient to have an immediate impact. "A lot of practical people around the labs thought it was an interesting theory but not very useful," said Edgar Gilbert, who went to Bell Labs in 1948—in part to work alongside Shannon. Vacuum-tube circuits simply could not handle the complex codes needed to approach the Shannon limit, Gilbert explained. Shannon's paper even received a negative review from J. L. Doov, a prominent mathematician at the University of Illinois in Urbana-Champaign. Historian William Aspray also noted that in any event the conceptual framework was not in place to permit the application of information theory at the time.

> His classic paper received a negative review from a prominent mathematician

Not until the early 1970s—with the advent of high-speed integrated circuits—did engineers begin fully to exploit information theory. Today Shannon's insights help shape virtually all systems that store, process, or transmit information in digital form—from compact discs to supercomputers, from facsimile machines to deep-space probes such as Voyager.

Solomon W. Golomb, an electrical engineer at the University of Southern California in Los Angeles and a former president of the IEEE Information Theory Society, thinks Shannon's influence cannot be overstated. "It's like saying how much influence the inventor of the alphabet has had on literature," Golomb remarked.

INFORMATION THEORY AND RELIGION. Especially early on, however, information theory captivated an audience much larger than the one for which it was intended. People in linguistics, psychology, economics, biology, even music and the arts sought to fuse information theory to their disciplines.

John R. Pierce, a former co-worker of Shannon who is now a professor emeritus at California's Stanford University, has compared the "widespread abuse" of information theory to that inflicted on two other profound and much misunderstood scientific ideas: Heisenberg's uncertainty principle and Einstein's theory of relativity.

Some physicists went to extraordinary lengths to prove that the entropy of information theory was mathematically equivalent to the entropy of thermodynamics. That turned out to be true but of little consequence, according to Bell Labs veteran David Slepian, a former colleague of Shannon at the laboratories who was also a seminal figure in information coding. Many engineers, too, "jumped on the bandwagon without really understanding" the theory, Slepian said. Shannon's work inspired the formation of the IEEE Information Theory Society in 1956, and subgroups dedicated to economics, biological systems, and other applications soon formed. In the early 1970s, the *IEEE Transactions on Information Theory* published an editorial, titled "Information Theory, Photosynthesis, and Religion," deploring the over-extension of Shannon's theory.

Shannon, while also skeptical of some of the uses of his theory, was rather free-ranging in his own investigations. In the 1950s, he did living-room experiments on the redundancy of language with his wife, Betty, who was a Bell computer scientist, Bernard Oliver, another Bell scientist (and a former IEEE president), and Oliver's wife. One person would offer the first few letters of a word, or words in a sentence, and the others would try to guess what came next. Shannon also directed an experiment at Bell Labs in which workers counted the number of times various letters appeared in a written text, and their order of appearance.

Moreover, Shannon has suggested that applying information theory to biological systems, at least, may not be so far-fetched. "The nervous system is a complex communications system, and it processes information in complicated ways," he said. When asked whether he thought machines could "think," he replied: "You bet. I'm a machine and you're a machine, and we both think, don't we?"

Indeed, Shannon's work on information theory and his love of gadgets led to a precocious fascination with intelligent machines. Shannon was one of the first scientists to propose that a computer could compete with humans in chess; in 1950 he wrote an article for *Scientific American* explaining how that task might be accomplished.

Shannon did not restrict himself to chess. He built a "mind-reading" machine that played the game of penny-matching, in which one person tries to guess whether the other has chosen heads or tails. A colleague at Bell Laboratories, David W. Hagelbarg-

er, built the prototype; the machine recorded and analyzed its opponents' past choices, looking for patterns that would foretell the next choice. Because humans almost invariably fall into such patterns, the machine won more than 50 percent of the time. Shannon then built his own version of the machine and challenged Hagelbarger to a now legendary duel.

He also constructed a machine that could beat any human player at a board game called hex, which was popular among the mathematically inclined a few decades back. Actually, Shannon had customized the board so that the human player's side had more hexes than the other; all the machine had to do to win was take the center hex and then match its opponent's moves thereafter.

The machine could have moved instantly, but to convey the impression that it was pondering its next move, Shannon added a delay switch to its circuit. Andrew Gleason, a brilliant mathematician from Harvard, challenged the machine to a game, vowing that no machine could beat him. Only when Gleason, after being soundly thrashed, demanded a rematch did Shannon finally reveal the machine's secret.

> Shannon's poem, 'A Rubric on Rubik's cube,' was set to music

In 1950 Shannon created a mechanical mouse that could learn how to find its way through a maze to a chunk of brass cheese, seemingly unassisted. Shannon named the mouse Theseus, after the mythical Greek hero who slew the Minotaur and found his way out of the dreaded labyrinth. Actually, the "brains" of the mouse were contained in a bulky set of vacuum-tube circuitry under the floor of the maze; the circuits controlled the movement of a magnet which in turn controlled the mouse.

When in 1977 the editor of *IEEE Spectrum* challenged readers to create a "micromouse" whose "brains" were self-contained, who could through trial and error solve a maze, and who could then learn through its mistakes and get through the maze in a repeat attempt without error, a former colleague of Shannon called *Spectrum* and insisted that Shannon had built such a micromouse two decades earlier.

Knowing the technology of the '50s would not have permitted it, the editor nevertheless called Shannon, who laughed, saying he had fooled a lot of people as he took his "smart" mouse around the country. The drapes around the table that hid the vacuum tubes and lead-screw machinery were vital, he chuckled. When *Spectrum* ceremoniously presented its Amazing Micromouse Maze Contest awards in 1979, Shannon got Theseus down from the attic, loaded him into his station wagon, and put him on display alongside the lineup of contending micromice.

Asked about prospects for artificial intelligence, Shannon noted that current computers, in spite of their extraordinary power, are still "not up to the human level yet" in terms of raw information processing. Simply replicating human vision in a machine, he points out, remains a formidable task. But he added that "it is certainly plausible to me that in a few decades machines will be beyond humans."

UNIFIED FIELD THEORY OF JUGGLING. In 1956 Shannon left his permanent position at Bell Labs (he remained affiliated for more than a decade) to become a professor of communications science at MIT. In recent years, his great obsession has been juggling. He has built several juggling machines and devised what may be the unified field theory of juggling: if B equals the number of balls, H the number of hands, D the time each ball spends in a hand, F the time of flight of each ball, and E the time each hand is empty, then $B/H = (D + F)/(D + E)$.

(Unfortunately, the theory could not help Shannon juggle more than four balls at once. He has claimed his hands are too small.)

Shannon has also developed various mathematical models to predict stock performance and has tested them—successfully, he said—on his own portfolio.

He has even dabbled in poetry. Among his works is a homage to the Rubik's Cube, a popular puzzle during the late 1970s. The poem, "A Rubric on Rubik's Cubics," is set to the tune "Ta-Ra-Ra-Boom-De-Aye." One verse goes: "Respect your cube and keep it clean./Lube your cube with Vaseline./Beware the dreaded cubist's thumb,/The callused hand and fingers numb./No borrower nor lender be./Rude folk might switch two tabs on thee,/The most unkindest switch of all,/Into insolubility. [Chorus] In-sol-u-bility./The strangest place to be./However you persist/Solutions don't exist."

Shannon himself had a genius for avoiding that "strangest place," according to Elwyn Berlekamp, who studied under him at MIT and co-wrote several papers with him. "There are do-able problems that are trivial, and profound problems that are not do-able," Berlekamp explained. Shannon had a "fantastic intuition and ability to formulate profound problems that were do-able."

However, after the late 1950s, Shannon published little on information theory. Some former Bell colleagues suggested that by the time he went to MIT Shannon had "burned out" and tired of the field he had created.

But Shannon denied that claim. He said he continued to work on various problems in information theory through the 1960s, and even published a few papers, though he did not consider most of his investigations then important enough to publish. "Most great mathematicians have done their finest work when they were young," he observed.

In the 1960s Shannon also stopped attending meetings dedicated to the field he had created. Berlekamp offered one possible explanation. In 1973, he recalled, he persuaded Shannon to give the first annual Shannon lecture at the International Information Theory Symposium, but Shannon almost backed out at the last minute. "I never saw a guy with so much stagefright," Berlekamp said. "In this crowd, he was viewed as a godlike figure, and I guess he was worried he wouldn't live up to his reputation."

Berlekamp said Shannon eventually gave an inspiring speech, which anticipated ideas on the universality of feedback and self-referentiality in nature.

Shannon nevertheless fell out of sight once again. But in recent years, encouraged by his wife, he has begun to drop in on small meetings and to visit various laboratories where his work is carried on.

In 1985 he made an unexpected appearance at the International Information Theory Symposium in Brighton, England. The meeting was proceeding smoothly, if uneventfully, when news raced through the halls and lecture rooms that the snowy-haired man with the shy grin who was wandering in and out of the sessions was none other than Claude Shannon. Some of those at the conference had not even known he was still alive.

At the banquet, the meeting's organizers somehow persuaded Shannon to address the audience. He spoke for a few minutes and then—fearing that he was boring his audience, he recalled later—pulled three balls out of his pockets and began juggling. The audience cheered and lined up for autographs. Said Robert J. McEliece, a professor of electrical engineering at the California Institute of Technology and chairman of the symposium: "It was as if Newton had showed up at a physics conference."

TO PROBE FURTHER. *The Collected Papers of Claude E. Shannon* (tentative title), edited by N.J.A. Sloane and A.D. Wyner will be published sometime during 1992 (publisher undecided). Shannon's seminal article, "The Mathematical Theory of Communication," along with several others of his important papers, is reprinted in *Key Papers in the Development of Information Theory,* edited by David Slepian, IEEE Press, 1974 (republished 1988).

ABOUT THE AUTHOR. John Horgan is an editor for *Scientific American*. Among the articles he wrote while he was with *IEEE Spectrum* were "Thwarting the information thieves" (July 1985), "Safeguarding the national security" (November 1985), and "Underground nuclear weapons testing" (April 1986). ◆

Books

(Continued from p. 16)

from the world of high-profile, powerful-computer-system start-ups, a limitation that may reduce their impact for many first-time entrepreneurs. Nonetheless, this perspective in no way affects the truth and significance of the basic prescriptions that he describes, and on which he bases his diagnostic.

Bell is really at his best when he is talking about the history and future of the information processing industry. In attributing its competitive decline in the world, however, to the preponderance of MBA holders and other financial (ostensibly nonengineering) types in positions of authority, he is on shaky ground. Most of these MBAs are also engineers, so there must be other reasons for the decline as well. But Bell's book is fun, opinionated, readable, and likely to help the engineer-entrepreneur.

Here's my advice to the prospective entrepreneur: read both books in rapid succession, and test your proposed venture against the wisdom of these extraordinary authors.

Gordon Baty is a partner in Zero Stage Capital Co., a Cambridge, Mass.-based venture capital firm. Before joining Zero Stage, he was founder or chief executive officer of technology start-up companies in the fields of industrial automation, computer peripherals, and energy. He taught entrepreneurship for many years in the MBA program at Northeastern University, Boston, and is the author of Entrepreneurship for the Nineties *(Prentice-Hall, Englewood Cliffs, N.J., 1990).*

Coordinator: Glenn Zorpette

Recent Books

Handbook of Quality Integrated Circuit Manufacturing. *Zorich, Robert*, Academic Press, San Diego, Calif., 1991, 583 pp., US $89.95.

Introductory Electronic Devices and Circuits: electron flow version, 2nd edition. *Paynter, Robert T.*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 1031 pp., $50.67.

Fiber Optic Sensors: an introduction for engineers and scientists. Ed. *Udd, Eric,* John Wiley & Sons, Somerset, N.J., 1991, 476 pp., $69.95.

The 68000 and 68020 Microprocessors: architecture, software, and interfacing techniques. *Triebel, Walter A.*, and *Singh, Avtar,* Prentice-Hall, Englewood Cliffs, N.J., 1991, 477 pp., $54.

Beginner's Guide to Reading Schematics, 2nd edition. *Traister, Robert J.*, and *Lisk, Anna L.*, Tab Books, Blue Ridge Summit, Pa., 1991, 129 pp., $10.95.

READER GUIDE TO PRODUCTS AND SERVICES

FEDERAL R&D BUDGET REPORTS

The IEEE-United States Activities' Technology Policy Council has released two new reports. One is the "Research and Development Initiatives in the National Defense Authorization Act for FY 1992-1993," an 11-page report that highlights bill provisions authorizing RDT&E funding levels, restructuring the Strategic Defense Initiative, liberalizing the rules for independent research and development, and promoting the development of critical and "dual-use" technologies.

The second is the Technology Policy Council's annual report, "Electrotechnology in the Federal FY 1993 Research and Development Budget." This report provides an overview of the Bush administration's 1993 Federal Fiscal Year budget request for R&D and outlines key issues that will influence the congressional budget authorizations and appropriations.

For complimentary copies of both reports, CIRCLE #83 on the Reader Service Card.

MICROFICHE

All current IEEE technical periodicals are available in both printed and microfiche editions. The price of a microfiche subscription is the same as for the printed edition and includes first-class postage within North America and air mail to subscribers outside of North America. Subscribe to *both* the printed and microfiche version of any IEEE periodical and get a 50 percent discount on the microfiche portion of that subscription.

For a complete listing of periodicals, subscription prices (both printed and microfiche), and availability and prices of single issues, please call 1-800-678-IEEE (908-981-0060 outside the United States).

NEW IEEE VIDEO
Wireless Communications

Sponsored by Virginia Polytechnic Institute and State University's Mobile & Portable Radio Research Group (MPRG) and the Division of Continuing Education, this new video was made in cooperation with the IEEE Communications Society and the IEEE Vehicular Technology Society. Presenters: Donald Cox of Bellcore, David Goodman of Rutgers University's Winlab, Larry Milstein of the University of California at San Diego, John Proakis of Northeastern University, Don Schilling of City College of New York, D.R. Vaman of Stevens Institute of Technology, Joseph McGeehan of Bristol's Center for Telecommunications Research, Allen Salmasi of Qualcomm, Bruce Tuch of NCR, Tien Hou of AT&T, Chandos Ripinski of LACE, Greg Vatt of Motorola, Roger Newell, publisher of *Microcell Report*, and Stuart Meyer, past president of the IEEE Vehicular Technology Society.

In this symposium, standards body participants, researchers from industry, and engineering faculty from around the globe represent the broad range of interests and activities in wireless communications, including: radio local-area networks (RLANs), personal communications networks (PCNs), digital cellular radio, and low earth orbit (LEO) satellites. Recent technological advances in each of these areas, and how these different systems will compete with or complement each other in the future, will be some of the many topics considered during this video symposium.

Product No.	ISBN	Member	List
HV0239-4	0-7803-0318-0	$295.00	$395.00

Recording Date	Run Time	Standard
6/91	7-12 Hours/ 4-6 Tapes	NTSC, PAL

To order, call 1-800-678-IEEE; fax, 1-800-981-9667. Outside the United States, call 908-981-0060.

For more information, CIRCLE #82 on the Reader Service Card.

EMPLOYMENT GUIDE FOR ENGINEERS AND SCIENTISTS

IEEE-United States Activities has published a revised, expanded third edition of the popular *Employment Guide for Engineers and Scientists*. This two-volume set includes practical advice on the job marketplace, the preparation and use of résumés, the use of employment and outplacement agencies, salary and benefit expectations, and career-planning strategies. It contains a directory of companies that employ IEEE members, with contacts where available. Unemployed U.S. nonstudent members may receive a complimentary copy of this publication by writing the IEEE-USA office, 1828 L St., N.W., Suite 1202, Washington, D.C. 20036-5104. Include membership number with request.

For more information, CIRCLE #81 on the Reader Service Card.

NEW!
1991 Robotics and Automation Conference Video Proceedings

The conference video proceedings of last year's Robotics and Automation Conference provides a unique opportunity to actually see new and significant experimental work and demonstrations in robotics and automation. A single video program was produced

(Continued overleaf)

READER SERVICE (CIRCLE NUMBERS)

1 PRODUCT INFORMATION

1	10	19	28	37	46	55	64	73	82	91	100	109	118	127	136	145	154	163	172
2	11	20	29	38	47	56	65	74	83	92	101	110	119	128	137	146	155	164	173
3	12	21	30	39	48	57	66	75	84	93	102	111	120	129	138	147	156	165	174
4	13	22	31	40	49	58	67	76	85	94	103	112	121	130	139	148	157	166	175
5	14	23	32	41	50	59	68	77	86	95	104	113	122	131	140	149	158	167	176
6	15	24	33	42	51	60	69	78	87	96	105	114	123	132	141	150	159	168	177
7	16	25	34	43	52	61	70	79	88	97	106	115	124	133	142	151	160	169	178
8	17	26	35	44	53	62	71	80	89	98	107	116	125	134	143	152	161	170	179
9	18	27	36	45	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180

MEMBERSHIP INFORMATION *300 Regular 301 Student*

Print or Type only
Name ______________________ Title ____________

Company ______________________________

Address ______________________________

City ______________ State ________ Zip __________

Country ____________ Business Phone ____________

If this represents a change in address, please fill out form on p. 9

3 ADDITIONAL COMMENTS

____

____

I would like: ______________________________

DELIVERY: I received this issue ______________ (date).

For faster information, fax this card to 413-637-4343

4

Void after July 1, 1992 *Void overseas August 1, 1992*

READER FEEDBACK (CIRCLE NUMBERS)

2 EDITORIAL MATTER

Article/Item	Comment: Too simple	Just right	Too detailed
Iraq's nuclear program	01	02	03
Nonproliferation status	04	05	06
Focus report: workstations			
Users' survey	07	08	09
Vendors' survey	10	11	12
Add-ons and peripherals	13	14	15
ICs' impact	16	17	18
Network management	19	20	21
Newslog	22	23	24
EEs' tools & toys	25	26	27
Legal aspects	28	29	30
Graphics	31	32	33
Engineer at large	34	35	36

Did you find this material stimulating or thought-provoking?

Item	Yes	No
Spectral lines	37	38
Forum	39	40
Books	41	42

READER GUIDE TO PRODUCTS AND SERVICES

when 32 videos were selected from the 66 entries submitted by the international community. The program is grouped into the following eight categories: Manipulator Design, Manipulator Control, Automation, Tele-Robotics, Sensing, Vehicles, Robotic Hands, and Walking Machines.

Product No.	ISBN	Member	List
HV0214-7	0-87942-546-6	$69.95	$109.95

Recording Date	Run Time	Standard
1991	65 Minutes/1 Tape	NTSC, PAL

To order, call 1-800-678-IEEE; fax, 1-908-981-9667. Outside the United States, call 908-981-0060.

For more information, CIRCLE #84 on the Reader Service Card.

IEEE LAN/MAN

Standards Update Service

Implementing the most current, approved IEEE standards is critical to remaining competitive in today's local-area network/metropolitan-area network (LAN/MAN) industry. But many times, it's difficult for you or your organization to learn exactly when a new IEEE LAN/MAN standard has become available—or how to get a copy. In response, the IEEE introduced its LAN/MAN Standards Update Service.

Enroll today and you'll automatically receive one copy of each newly approved IEEE LAN/MAN standard as soon as it's published—at a guaranteed 40 percent discount, invoiced with your shipment. This is a tremendous savings that you just won't find anywhere else! This service does not apply to the purchase of existing IEEE LAN/MAN standards.

Enjoy the ease and reliability of receiving the newest LAN/MAN standards as soon as they become available! To sign up, call Renee Owens, IEEE Customer Service, at 908-562-5432.

For more information, CIRCLE #85 on the Reader Service Card.

New IEEE Videoconference Program

May 28, 1992

ENVIRONMENTAL ISSUES AND IMPACT TO ENGINEERS

Health and environmental issues present some of the toughest challenges that electrical and electronics engineers will face in the near future. The solutions will require alterations in our day-to-day work procedures and may lead to major changes in the way electronic engineering is practiced.

This videoconference will look at these changes—many of them controversial—in a lively yet practical way. We will focus on issues that must be addressed early in the electronics design phase.

All engineers will need to focus on health and environmental requirements as new processes are defined and new products are brought to market. The impact of environmental issues on your applications make this videoconference key viewing for electronics and electrical engineers worldwide.

Lead Presenter: Diana J. Bendz, Director of Safety, Chemical Management, and Environmental Programs, IBM Corp., Purchase, N.Y.

Corporate rate (single site): $1,800 per broadcast.
University rate (single site): $850 per broadcast.

Questions? Call Judy Brady, IEEE Marketing, 908-562-3991.

For more information, CIRCLE #86 on the Reader Service Card.

How to keep up? ESAP!

Keeping up and finding ways to keep up is an almost insurmountable challenge for the engineer in industry and academia in today's environment. The IEEE has developed the Engineering Skills Assessment Program (ESAP), a system with speedy, "short circuit" paths for circulating skill and knowledge requirements among industry, academia, and the engineer. The system provides for self-assessment and guidance in and out of the field, and is a viable means for nurturing lifelong learning.

Twenty-one of an anticipated 100 fields have been prioritized for development using criteria based on membership interest as determined by the Technical Interest Profile (TIP). They are:

- Real-Time Systems
- Software Reliability Matrix
- Expert-System Shells
- Engineering Management
- Communications Switching
- Power Electronics
- Radar Engineering
- Remote Sensing
- Space Communications
- VLSI (Very Large-Scale Integration)
- Navigation
- Control Systems
- Acoustics, Speech, and Signal Processing
- Reliability
- Analog Circuits
- Lasers and Lightwaves
- Electromagnetic Compatibility
- Intellectual Property Management
- Antennas
- Digital Signal Processing
- Microwave Engineering

For more details and ordering information, CIRCLE #87 on the Reader Service Card.

PRODUCT PROFILES

The PRODUCT PROFILES advertising section provides a distinctive focus on both new and commercially established products and services that offer practical solutions for engineering and scientific professionals in today's fast-paced, rapidly changing high-tech environment.

Employment opportunities

Organizations seeking engineers and scientists describe their various openings in the following advertising section

In order to conform to the Age Discrimination in Employment Act and to discourage age discrimination, IEEE may reject any advertisement containing any of these phrases or similar ones, "recent college grads," "1–4 years maximum experience," "up to 5 years experience," or "10 years maximum experience." IEEE reserves the right to append to any advertisement, without specific notice to the advertiser, "Experience ranges are suggested minimum requirements, not maximums." IEEE assumes that, since advertisers have been notified of this policy in advance, they agree that any experience requirements, whether stated as ranges or otherwise, will be construed by the reader as minimum requirements only. While IEEE does not ban the use of the term "entry level," its use is discouraged since, to some, it connotes an age rather than an experience designation. IEEE accepts employment advertising to apprise its members of opportunities. Interested parties should be aware that the political and humanistic values of certain advertisers may differ from their own. IEEE encourages employers to offer salaries that are competitive, but occasionally a salary may be offered that is significantly below currently acceptable levels. In such cases the reader may wish to inquire of the employer whether extenuating circumstances apply.

MANAGER

Power Systems Technology Program

Oak Ridge National Laboratory (ORNL) is seeking a senior staff member to manage its well-established Power Systems Technology Program. This program provides technical support and subcontract management for the U.S. Department of Energy's goal to enhance the capacity of the nation's electric transmission system. The program currently is five professional staff members with an annual budget of about $3 million.

The program manager is expected to provide leadership and vision for the program, and clearly communicate the direction of the research program to the sponsors and other interest groups. The manager should assist sponsors in formulating and executing a basic and applied research program in electric power systems of transmission and distribution, and related areas including generation, renewable energy sources, storage, and environmental issues. The manager will work closely with PMAs and with EPRI and other utility organizations, and will participate on industry-wide committees.

The candidate should have an MS or higher degree and relevant industrial experience with proven competence in research in the area of electric power systems. Experience in the electric utility industry and/or electric power manufacturing/ vendor industry and 10-15 years of participation in research and project management experience are preferable.

Strong interpersonal skills and ability to work with people in a leadership role as well as the ability to effectively communicate with peer groups and industry/government leaders is essential. Strong oral and written English skills are essential. Proven recognition in the power engineering field, established through professional/industry activities is desirable.

Qualified candidates should contact: J. L. Trimble, Oak Ridge National Laboratory, Dept. IS, Building 4500 N., MS 6217, P.O. Box 2008, Oak Ridge, TN 37831-6217.

ornl

ORNL is managed by Martin Marietta Energy Systems, Inc. for the US Department of Energy and is an equal opportunity employer. US citizenship is required.

CLASSIFIED

ADVERTISING RATES

DISPLAY ADVERTISING RATES—call Theresa Fitzpatrick at 212-705-7579

CLASSIFIED

Positions open—$36.00 per line, not agency-commissionable

Positions wanted—$36.00 per line, a 50% discount for IEEE members who supply their membership numbers with advertising copy

All classified advertising copy must be received by the 25th of month, two months preceding date of issue. No telephone orders accepted. For further information contact Francesca Silvestri, 212-705-7578.

The following listings of interest to IEEE members have been placed by educational, government, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

Academic Positions Open

Princeton University: the department of Electrical Engineering invites applications for full time, tenure-track faculty position. The disciplines of particular interest are complex systems, specializing in areas such as robotics, manufacturing systems, networks, and stochastic or nonlinear systems; and signal processing, specializing in areas such as video and image processing. Please send a complete resume, a description of research and teaching interests, and names of three references to Professor Stuart Schwartz, Chair, Dept. of EE, Princeton University, Princeton, NJ 08544-5263. Princeton University is an equal opportunity/affirmative action employer.

Electrical/Computer Faculty Positions. The Department of Electrical and Computer Engineering at LSU invites applications for anticipated tenure-track and visiting faculty positions at the assistant, associate and full professor levels available August 1992 in the following areas: electric energy systems, including power electronics; solid state electronics; systems, including automatic control, communications and signal processing; and computers, including microprocessors, distributed processing systems and special purpose architectures. A PhD or equivalent degree and potential for excellence in teaching and research are necessary. The positions involve teaching graduate and undergraduate courses in electrical and/or computer engineering and research in areas of individual interest. Completion of all PhD requirements is necessary before employment begins. Salary is competitive and commensurate with qualifications and experience.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Release time and resources are provided in order to enhance the development of a quality research program. Opportunities for summer support are available. Send resume, names of three references, a statement of teaching and research interests, and verification of employment eligibility in compliance with the Immigration Reform and Control Act of 1986 to: Alan H. Marshak, Chairman, Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA 70803-5901. LSU is an Equal Opportunity Employer.

Drexel University. The Department of Electrical Engineering and Computer Engineering expects to have tenure-track and visiting faculty positions for the academic year 1992-1993. At the present time we are seeking individuals with strong interest in engineering education and academic research, whose areas of specialization are in the general area of communications, telecommunications, mobile communications, and networking. Applicants must have a Ph.D. The ECE Department has active groups in the areas of System Theory, Computer Engineering, Power Systems and Electrophysics. Send Curriculum Vitae, including the names of five references, to: Dr. Bruce A. Eisenstein, Head, Department of Electrical and Computer Engineering, Drexel University, Philadelphia, PA 19104. Immigration status of non-US citizens should be stated. Drexel University is an equal opportunity/affirmative action employer, and welcomes applications from women and minorities.

Electronics and Computer Engineering Technology: The University of Arkansas at Little Rock, Department of Engineering Technology invites applications for two tenure-track faculty positions at the Assistant Professor level, one in Electronics and the other in Computer, beginning Fall 1992. For the Electronics position, preference will be given to applicants with specialization in one or more of the following areas: Analog Electronics, Signal Processing, or Control Engineering. For the Computer position, preference will be given to applicants with specialization in the following areas: Computer Hardware and Architecture, and Microprocessor Interfacing. However, well qualified applicants with specializations in other areas will be considered. Minimum qualifications for these positions include a Master's Degree in Electrical or Computer Engineering, and at least three years of full-time relevant industrial experience. Applicants should possess a commitment to excellence in teaching, a strong interest in developing laboratories and a desire to pursue individual and/or interdisciplinary research in the College of Science and Engineering Technology. Please send a resume and the names and telephone numbers of three references to: Dr. H.C. Patangia, Chairman, Department of Engineering Technology, University of Arkansas at Little Rock, 2801 S. University, Little Rock, AR 72204. Applications will be accepted until the positions are filled. University of Arkansas at Little Rock is an affirmative action/equal employment opportunity employer. Applications from minorities and women are strongly encouraged. Under Arkansas law, all applications are subject to disclosure.

University of Iowa: Applications are invited for a tenure-track assistant professor position in the Department of Biomedical Engineering. Candidates should have expertise in the disciplines of cardiovascular biofluid mechanics, bioinstrumentation and medical imaging. An earned Ph.D. in Biomedical Engineering (or allied fields) is required. Faculty responsibilities include effective classroom teaching at the undergraduate and graduate levels, developing curricula and laboratories, supervising M.S. and Ph.D. student research, publishing journal articles, and developing and maintaining an externally funded research program, preferably of an interdisciplinary nature involving collaboration with faculty in the School of Medicine. Demonstrated teaching and research abilities are highly desirable. Interested candidates should submit a letter stating their professional interests and a current curriculum vitae, and have three letters of reference sent to: Chair, Faculty Recruiting Committee, Department of Biomedical Engineering, The University of Iowa, Iowa City, Iowa 52242. Applications will be reviewed starting April 22, 1992, but will be accepted until the position is filled. Women and minorities under-represented in the engineering profession are especially encouraged to apply. The University of Iowa is an Equal Opportunity/Affirmative Action Employer.

Graduate Research Assistants. The Center of Microelectronics Research (CMR) at the University of South Florida is seeking graduate research assistants to support research activities in the areas of microelectronic materials and defects, semiconductor processing and manufacturing, VLSI/ULSI/WSI architecture, circuit design, design automation and test. Successful applicants will be required to pursue a Ph.D. Program in E.E., C.S., or Physics. Stipends are available in the range of $12K to 17K (half time) for a full calendar year beginning July 1992, with tuition waivers available. Applicants must have an excellent academic record and a minimum of a Bachelors degree in an appropriate discipline. U.S. citizenship is a requirement for several of the anticipated positions. CMR research funding totals $12M over the past two years from state, DoD and industrial funding sources. USF is an Affirmative Action/Equal Opportunity Employer. Resumes should be directed to Dr. Earl Claire, CMR/USF College of Engineering, MS ENG 118, 4202 E. Fowler Avenue, Tampa, FL 33620.

The University of Alabama at Birmingham—W.R. Bunn Professorship in Telecommunications. The University of Alabama at Birmingham requests nominations and applications for the W.R. Bunn Professorship in Telecommunications. This distinguished position is open to qualified applicants who have significant background and experience in the telecommunication fields of high-speed bulk data transmission, high performance optical switching and computing, intelligent systems, and applications of communications theory. The person appointed to this position should have a national reputation, a record of identifying and soliciting funding opportunities, and the capability of establishing research teams. The W.R. Bunn Professorship in Telecommunications will be funded by the BellSouth Foundation (and the State of Alabama) to encourage education and research in the field of telecommunications. The applicant must understand and be significantly involved in the structure and culture of the telecommunications industry. The applicant should have an earned doctorate and a record of teaching, service, and scholarly activity to justify appointment at the rank of full professor. In addition, this person should have the appropriate interpersonal skills necessary to operate within an interdisciplinary academic environment that has a significant industry orientation. Applications will be evaluated as received with a goal of an appointment during 1992. Inquiries, nominations, and applications should be directed to Dr. William A. Sibley, Vice President for Academic Affairs, The University of Alabama at Birmingham, UAB Station, Birmingham, AL 35294-1250. The University of Alabama at Birmingham is an affirmative action, equal opportunity employer and educational institution.

Hofstra University—Position available in Electrical/Computer Engineering courses responsible for teaching in the EE Program. Possibility of hardware courses in the CSC Department. Hofstra is a private University located 25 miles from New York on Long Island. Salary and rank commensurate with experience. Resume and names of three references to Dr. M. David Burghardt, Engineering Dept., Hofstra, Hempstead, N.Y. 11550. Women and minorities are encouraged to apply. AA/EOE.

Faculty Positions in Georgia Tech. The School of Electrical Engineering seeks applicants for tenure track faculty positions. Ph.D. in EE, or equivalent, and clear potential for distinguished performance in teaching and research are required. Areas of special need are for senior level faculty in computer engineering, telecommunications or experimental microelec-

KEMA-USA
Executive Vice President

As a leader in providing high-tech equipment certification and Quality Assurance services for the European Community, KEMA-USA has established KEMA Certified Quality Inc. to assist U.S. manufacturers to market electrical/electronics, medical and other high-tech products in Europe.

We are searching for a qualified executive to help introduce our services to U.S. industry, and to provide leadership and direction to this activity. This individual will work closely with customers and with NV KEMA Europe to assist our customers in complying with ISO 9000 series and related standards.

The successful candidate for this position must have marketing and ISO 9000 Quality Systems experience, a Total Quality oriented attitude, and the energy and ability to manage a startup business operation.

This position offers competitive benefit programs and salary commensurate with experience. Confidential consideration will be given to all resumes submitted by interested candidates to:

KEMA-USA
Attn: Mr. B.J. Cavanaugh
4379 County Line Road
Chalfont, PA 18914
FAX (215) 822-4267

NO PROFESSIONAL RECRUITERS, PLEASE

An Equal Opportunity Employer – M/F

Research Positions
Keweenaw Research Center
Applied Research Group

Michigan Technological University

Research Positions—Keweenaw Research Center (KRC): The KRC Applied Research Group invites applications for the positions of Research Engineer/Scientist, Senior Computer Programmer, and Computer Programmer. KRC is a research branch of Michigan Technological University, located in Upper Michigan near Lake Superior. The Applied Research Group is principally involved in modeling and measuring the infrared signatures of ground targets and backgrounds.

Research Engineer/Scientist: To perform research in thermal imaging systems, at KRC. Master of Science degree in Mechanical Engineering or a related field, or an equivalent combination of education and experience. Must be familiar with computer modeling and heat transfer, and have a high degree of competence in FORTRAN and/or C programming. Previous experience is desirable but not necessary. Must be a United States citizen and be able to obtain a DoD security clearance.

Computer Programmer: To work at the Tank-Automotive Command facilities in Warren, Michigan. B.S. in science or engineering plus 2–5 years experience, and familiarity with the following: HP/SUN Systems, UNIX, DOS, C, INGRES, X-Windows, Graphics User Interface Development, and Instrumentation Programming.

Senior Computer Programmer: To work at the Tank-Automotive Command facilities in Warren, Michigan. M.S. in science or engineering plus 5–10 years experience, and experience with the following HP/Sun Systems, UNIX, DOS, C, INGRES, X-Windows, MOTIF, Graphics User Interface Development, and Instrumentation Programming. Some knowledge of Allegro Common LISP by FRANZ Inc. is desirable.

Send vita including publication list and references to: Keweenaw Research Center, ATTN: Applied Research Group, Michigan Technological University, 1400 Townsend Drive, Houghton, Michigan 49931-1295. Michigan Technological University is an equal opportunity, affirmative action employer.

Electrical Engineering

At Fermi National Acclerator Laboratory, our advanced research in particle physics, detectors, cryogenics, computer science and super conductivity, is uncovering new worlds —and new truths about the world we live in. Now, you can join our Research Division and develop interfaces and control modules for beamline control systems.

Responsibilities will include the design and development of analog and digital circuitry using VME (IEEE 1014), CAMAC (ANSI/IEEE Std 583-1982), and other bus standards, to interface all aspects of a real-time distributed processor control system, and supervision of a team of technicians. Qualified candidates will have at least 10 years experience in the design of low-level analog/digital circuitry including demonstrated competence designing and implementing embedded processor controllers and subsystems with emphasis on integration into a larger system, and a BSEE degree (MSEE preferred). Additionally, exposure to firmware design with Intel 386+ processors, LAN's CAD tools, and PLD's is desired.

We are located in a large campus-like setting just 40 miles west of downtown Chicago and will provide the right candidate with a competitive salary and a generous benefits package. For confidential consideration, please send your resume to **Mr. James L. Thompson, Employment Manager, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510.** An Equal Opportunity Employer M/F/H.

Fermilab

Advanced Technology Laboratories, a world leader in the design, manufacture and sale of diagnostic medical ultrasound systems is located just 20 minutes from Downtown Seattle in beautiful Bothell, Washington's progressive High-Tech corridor.

We are currently seeking a:

Senior Systems Engineer

Working in a team environment, the successful candidate will be responsible for state-of-the-art ultrasound system and beam-forming analysis and simulation, scanhead integration, and image parameters optimization and specification.

Requires a BSEE with 2+ years of related work experience, understanding of acoustic beam formation, signal theory, wave propagation theory, ultrasound scattering theory and knowledge of higher level programming languages. An advanced degree is highly advantageous.

Apply your talent where it can really make a difference. Send your resume to: **ATL, Attn: 12-P, P.O. Box 3003, Bothell, WA 98041-3003.** ATL is an equal opportunity employer and maintains a smoke free and drug free workplace.

Advanced Technology Laboratories™

KEMA POWERTEST

KEMA-Powertest, one of the largest independent high-power electrical testing laboratories in the U.S., is searching for the right person for the position of

LABORATORY TEST ENGINEER

This individual will prepare and conduct electrical and mechanical tests on all types of electrical distribution and transmission equipment. Experience in electrical test engineering, and ability to interact effectively with customers are necessary. While a post-graduate degree is desired, candidates must possess a degree in electrical engineering. Competitive benefit programs and salary commensurate with experience. Interested candidates may submit a resume in confidence to:

KEMA-Powertest
4379 County Line Road
Chalfont, PA 18914
Fax: (215) 822-4267

NO PROFESSIONAL RECRUITERS, PLEASE

An Equal Opportunity Employer – M/F

A Company Like You!

You're innovative, enthusiastic and confident you can make a difference. You're headed for the top of your field. So are we.

At Pacific Communication Sciences, Inc. (PCSI) we are pioneering some of the newest technologies in telecommunications. Right now we're working on advanced VLSI solutions for digital cellular, digital cordless (PCN), and wide-area wireless data systems. In the field of inter-networking, PCSI's DSP-based systems for transmission of compressed voice, fax, and data are bringing clear, low-cost communication to companies around the world.

We're looking for talented EE's and CS's at all degree levels with at least 5 years experience in any of the following:

• **RF CELLULAR INFRASTRUCTURES:** Expertise in design, implementation, installation and manufacture of radio subsystems for cellular telephony cell sites and mobile telephony base stations. • **RF CELLULAR:** Design low-cost compact RF modules for cellular applications, generate specs, expertise in design, implementation and manufacture of commercial cellular telephone radio subsystems. • **ANALOG ASIC:** Chips for communication architectures, advanced logic and analog IC design required. GDT, Compass, behavior langugages, prefer Verilog. • **DSP S/W:** Assembly, multiple processors, modem, speech, telephone applications. • **DIGITAL ASIC:** Gate level design, simulation, test vector generation, strong background in cellular, modem, coding theory, communication systems.
• **NETWORK S/W:** Design telecom networks, "C" PC DOS, SNA x.25, data compression, packet switching. • **H/W DESIGN:** Modem radio applications, design experience with DSPs, digital logic, microprocessors, prefer analog design and communications background.
• **VLSI PROJECT LEAD:** DSP H/W, VLSI architecture, time critical management. High volume mobile communication products. • **VOICE PROCESSING:** Real time implementation for voice compression (CELP) algorithms.

Clearly indicate the position for which you wish to be considered. Mail or FAX your resume to: PCSI, Attn: S.J. Otos, 10075 Barnes Canyon Road, San Diego, CA 92121, FAX 619/535-9235. EOE.

PCSI PACIFIC COMMUNICATION SCIENCES, INC.

tronics. Resumes and statements of interest should be addressed to: Roger P. Webb, School of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250. Immigration status of non-US citizens should be indicated. Georgia Tech is an equal opportunity/affirmative action employer.

Rice University, Houston, The Department of Electrical and Computer Engineering has an opening for a research associate in the area of laser plasma interaction. Desired qualifications: In addition to a PhD from a recognized university in the field, the applicant should have conducted research in laser and/or plasma physics and be familiar with general laboratory techniques in particular solid state and excimer laser technology. Furthermore, three or more years of research experience after the PhD in laser plasma interaction or a closely related field is desirable. Applicants should submit their resumes to: Dr. Roland Sauerbrey, Department of Electrical and Computer Engineering, Rice University, PO Box 1892, Houston, TX 77251. Rice University is an equal opportunity/affirmative action employer.

Tenure track position available in Bioengineering Program at Texas A&M University. PhD in Bioengineering or related field with expertise in bioinstrumentation required. Ability to teach undergrad and grad courses, develop independent research, and interact with other faculty, especially an ecological/environmental program, is needed. Send vitae and references to: Dr. Gerald Miller, Chairman, Bioengineering Program, Texas A&M University, Mail Stop 3120, College Station, TX 77843 by April 15. Equal Opportunity Employer.

Chairperson: Electrical and Computer Engineering. Candidate with proven research, teaching, program development and administrative record sought to provide leadership for the ECE department. NJIT is New Jersey's public technological university with nearly 7500 students pursuing baccalaureate through Ph.D. degrees in Newark College of Engineering, School of Architecture, College of Science and Liberal Arts, and School of Industrial Management. The university expends approximately $15 million annually in sponsored research, $1 million of which is in such ECE research areas as VLSI systems, computer networks, computer architecture, parallel processing, and intelligent systems. NJIT's campus is networked and computing intensive. Additional facilities include: interdisciplinary Center for Manufacturing Systems; new, state-of-the-art Microelectronics Center with class #10 cleanroom for integrated circuits fabrication, as well as optoelectronics, CAD, and microwave and lightwave engineering laboratories. Enrollment is highest of any ECE department in New Jersey and the New York metropolitan region; the department plays important roles in the profession and the community. Appropriate doctorate, solid credentials in research, publication and educational leadership required. Send resume to: Personnel Box ECEC. NJIT does not discriminate on the basis of sex, race, color, handicap, religion, national or ethnic origin or age in employment. New Jersey Institute of Technology, University Heights, Newark, NJ 07102.

Computer Scientist/Engineer—Tenure-Track F'92. The Wilkes School of Science & Engineering invites applications from individuals with Ph.D. or in its final stages who are interested in innovative teaching and research program involving students. Background in software engineering, networking, or AI is preferred. The School is known for its activities in computer adaptation in industry. Wilkes is a comprehensive university located in the Pocono resort area and was recently named as one of 16 supercities by a national publication. Ample opportunities are available for professional growth, and the School encourages ties with industry and government. Forward resume, transcripts, and references to: Dr. Redmond, Associate Dean, Wilkes University, Wilkes-Barre, PA 18766. Women and Minorities are encouraged to apply. AA/EEO.

Carnegie Mellon University—Information Networking Institute. Position: Director, Professional Education. The Information Networking Institute at Carnegie Mellon University conducts research and operates graduate and mid-career education programs which combine telecommunications, computer science and the strategic use of information technology for business. The Institute has an opening for a professional with business and professional educational experience in information networking or related areas. This unique position provides the opportunity for a highly motivated senior professional to work with world-class IN faculty and industry consultants to deliver professional education to a diverse set of senior technical managers and executives. The successful candidate will direct the Professional Education group, which currently offers a rigorous 14 week interdisciplinary program providing participants with the knowledge and skills critical to the innovation and implementation of state-of-the-art information network solutions. Responsibilities of this job include: new course design, development, and delivery, and continual enhancement and delivery of existing programs. This professional will also serve as a consultant to the INI Masters program, working with CMU faculty to advise, direct, and evaluate a comprehensive final case project. Strong interpersonal skills and extensive business experience is required. Salary commensurate with experience. Send resume and names and addresses of three references by April 30, 1992 to Casey Jones, Information Networking Institute, Carnegie Mellon University, Pittsburgh, PA 15213. Carnegie Mellon University does not discriminate and Carnegie Mellon University is required not to discriminate in admissions and employment on the basis of race, color, national origin, sex or handicap in violation of Title VI of the Civil Rights Act of 1964, Title IX of the Educational Act of 1972 and Section 504 of the Rehabilitation Act of 1973 or other federal, state, or local laws or executive orders. In addition, Carnegie Mellon University does not discriminate in admissions and employment on status or sexual orientation in violation of any federal, state, or local laws or executive orders. Inquires concerning application of this policy should be directed to the Provost, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213 (412) 268-6684, or the VP for Enrollment, (412) 268-2056.

Oral Roberts University invites applications from electrical/computer science engineers, Ph.D. preferred. ORU is a Charismatic Christian institution offering an undergraduate program in general engineering with emphasis in electrical, computer science, and mechanical engineering. Direct your enquiries to: Chairman, Engineering & Physics Dept., Oral Roberts University, Tulsa, OK 74171.

Old Dominion University. The Department of Electrical and Computer Engineering invites applications for a senior-level faculty position beginning August 1, 1992. Applicants should have demonstrated superior research ability in one or more areas of physical electronics, such as plasma engineering and opto-electronics, and are expected to establish a nationally-visible research program. Duties also include undergraduate and graduate teaching. Qualifications include a Ph.D. in electrical engineering or closely related area and research credentials suitable for appointment at the rank of Associate or Full Professor. Review of applications will begin April 1, 1992, and will continue until the position is filled. Please send applications, including full resume and names of three references, to: Dr. R.R. Mielke, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, Virginia 23529-0246. Old Dominion University is an Affirmative Action/Equal Opportunity Employer and requires compliance with the Immigration Reform and Control Act of 1986.

Oregon State University—The Department of Electrical and Computer Engineering invites applications for the following tenure-track faculty positions at all levels. Associate or Full Professor positions require a distinguished teaching

ISSA/NSA POLY

USE YOUR "TICKETS" FOR FASTER CAREER GROWTH

Put our 27+ years experience placing technical professionals to work for you. All fees paid. Nationwide opportunities in Communications, Defense, Intelligence, Computer, Satellites and Analytical Sciences. If you earn over $35,000, we have a better, more rewarding job for you ... right now. U.S. citizenship and ISSA/NSA POLY desirable. Call (301) 231-9000 or send your resume in confidence to: Dept. EA-I3EB or FAX to: (301) 770-9015.

WALLACH associates, inc.
Technical and Executive Search
Washington Science Center
6101 Executive Boulevard
Box 6016
Rockville, Maryland 20849-6016

Department of Electronics and Electrical Engineering

UNIVERSITY of GLASGOW

JAMES WATT CHAIR OF ELECTRICAL ENGINEERING

Applications are invited from persons with a distinguished record in any branch of Electrical or Electronic Engineering. The holder of the Chair will be expected to maintain and promote the academic and research excellence of the Department which presently holds a top Grade 5 UFC research rating.

The James Watt Chair is one of two established Chairs in the Department, in addition there are at present eight Titular Professors and 40 other academic staff, with around 450 undergraduates taking a variety of Honours degree courses. The principal current research interests of the Department are in Bioelectronics, Control Systems, Nanoelectronics, Optoelectronics, Power Electronics and Signal Processing.

Applications are equally welcome from those who have an academic or an industrial background.

Further particulars may be had from the Academic Personnel Office, University of Glasgow, Glasgow G12 8QQ, with whom applications (3 copies; 1 copy in the case of overseas applicants), giving the names and addresses of three referees, should be lodged on or before 30th April, 1992. In reply please quote ref. no. 7534.

The University is an equal opportunities employer.

POWER ELECTRONICS

DIRECTOR, OPERATIONS TO $150K

East Coast power supply manufacturer seeks technical business development professional to direct the company into new markets. Strong engineering and marketing background required.

DIRECTOR, R&D TO $100K+

Mid-Atlantic power supply manufacturer needs highly technical manager to lead development of supplies from 75 watts to 10kW. Exceptional career opportunity. MSEE and 10+ years' required.

POWER/ANALOG R&D TO $75K

Several opportunities for MSEE's and PhD's with R&D experience in any of the following areas: switch mode power supplies, magnetics, power IC's, EMI, ballasts, electronic lighting, filters, or microprocessor-based circuitry.

SR. MOTOR CONTROLLER ENG. TO $75K

Pacific NW company seeks engineer with 10+ years' AC&DC motor controller design. IGBT, bipolar background in 10-150kW range.

POWER SUPPLY DESIGN TO $70K

Nationwide opportunities for BS/MSEE's with experience in the design and development of commercial or military switch mode power supplies.

POWER TECHNOLOGY ASSOCIATES, INC.
1200 Providence Highway
Sharon, MA 02067
Attn: Rich Cardarella
Phone: (617) 784-4200
Fax: (617) 784-4302

ELECTRICAL ENGINEER

Sanofi Diagnostics Pasteur, Inc., formerly Kallestad Diagnostics, Inc., is a pacesetter in the design and development of medical diagnostic test kits and instrumentation. We currently have several Electrical Engineer opportunities available in Chaska, MN, a western suburb of Minneapolis.

We are looking for candidates with a B.S. in Electrical Engineering (MSEE preferred) plus a minimum of 7 years experience with real time microprocessor/microcontroller based digital control systems. Experience with analog circuitry, data acquisition, motion control, RFI, and CAD tools is highly desirable.

We are also looking for candidates with a minimum of 4 years experience in product development in addition to a B.S. (or M.S.) in Electrical Engineering. Analog design experience and sensor technology is essential; some digital experience desired. Experience with CAD tools highly desired.

We offer an excellent salary and benefits package including company-paid family medical insurance coverage, relocation assistance and a 401K plan, as well as the opportunity for continuing advancement within a dynamic multi-national organization. For confidential consideration, please send your resume to: **Sanofi Diagnostics Pasteur, Inc., Attn: Human Resources - MM, 1000 Lake Hazeltine Drive, Chaska, MN 55318.**

sanofi DIAGNOSTICS Pasteur

Equal Opportunity/Affirmative Action Employer

CLASSIFIED EMPLOYMENT OPPORTUNITIES

and research record appropriate for the title. Candidates should have an earned doctorate in Electrical or Computer Engineering and are expected to have a strong commitment to high quality undergraduate and graduate teaching and to the development of a sponsored research program. Two positions are in Computer Engineering. One opening is immediate and the other is anticipated for Fall 1992. Areas of activity include: computer architecture, parallel processing, VLSI array processing, performance modeling and analysis, data communication and computer networks. One position in the general area of Electronics is immediately available. Areas of interest include: electronic materials and devices, integrated circuits, VLSI, microwaves, and optoelectronics. One position in the area of Systems and Control will be open beginning Fall 1992. Areas of activity include: robust control, robotics, and real-time process control. Some background in communications and signal processing is desirable but not mandatory for this position. With a faculty of 25, the Department of ECE enrolls about 425 undergraduate and 120 MS/PhD students. High technology corporations such as Hewlett-Packard, Intel, Mentor Graphics, and Tektronix have major operation in the area and provide support for the electrical and computer engineering program. The Department has modern facilities housed in a new building. Located in the Willamette Valley 80 miles south of Portland, OSU and the city of Corvallis offer a beautiful and unspoiled environment and many cultural activities. Applications must include a comprehensive resume, a list of three to five professional references, and a letter of interest. Your letter must indicate clearly the position for which you are applying. Please send material to Chairman, ECE Search Committee, ECE Department, Oregon State University, Corvallis, OR 97331-3211. Review will begin immediately and continue until the positions are filled. Oregon State University is an Affirmative Action/Equal Opportunity Employer and complies with Section 504 of the Rehabilitation Act of 1973. OSU has a policy of being responsive to the needs of dual career couples.

Assistant Professor, Electrical Engineering—The Department of Electrical Engineering at the University of Delaware invites applications for an assistant professor in the area of electronic devices and materials. Applicants must have a Ph.D. in electrical engineering (or a closely related field). We seek candidates with extensive experience and ongoing interest in innovative semiconductor optoelectronic or high speed device fabrication and characterization. Candidates with a strong background in the application of electromagnetics to these areas are particularly encouraged to apply. The candidate must be committed to a career in teaching and experimental research. The Department has modern facilities for device processing and analysis, including a class 10 cleanroom with the necessary fabrication equipment, LPE and MBE reactors, a 50 GHz network analyzer and specialized laboratories with the instrumentation required for the evaluation of microwave and optoelectronic devices. Resumes including the names and addresses of three references should be submitted to Search Committee, Department of Electrical Engineering, University of Delaware, Newark, DE 19716. Review of applicants will begin April 15, 1992 and continue until position is filled. The University of Delaware is an Equal Opportunity Employer which encourages applications from qualified Minority Group Members and Women.

Post Doctoral Positions available in the Department of Electrical Engineering at Princeton University to conduct research in electronic materials, computer engineering, or information science and systems. Respond to Ms. Carol Desmond, Dept. Manager, Dept. of EE, B-210 E-Quad, Princeton University, Princeton, NJ 08544. Princeton is an Equal Opportunity/Affirmative Action Employer.

South Dakota State University; Assistant Professor in Electrical Engineering for Fall 1992. Tenure track contingent upon qualifications. Ph.D. in EE or related discipline; or MS in EE plus 30 additional graduate semester hours and 3 years full time relevant experience considered. Demonstrated expertise in Microelectronics materials and devices and/or Microprocessors and Logic Systems design; effective English communication and Interpersonal relations skills required. Prefer relevant significant industrial experience, earned BSEE degree from or evidence of significant teaching in an ABET accredited program, demonstrated effective teaching skills, record of sponsored research participation and potential to obtain external research funding. Application deadline May 15, 1992 or until position filled. For information and application form, write Dr. Virgil G. Ellerbruch, Department Head, Electrical Engineering Department, Box 2220, SDSU, Brookings, SD 57007-0194. SDSU is an AA/EEO employer (F/M).

George Mason University—Systems Engineering Department-School of Information Technology and Engineering. Professor, Systems Engineering. The Systems Engineering Department is seeking applicants for a tenured or tenured track position. Applicants should have a research background and/or experience in one or more of the following areas: systems design, systems theory, requirements definition, functional decompositions, systems modeling, architecture specification and evaluation, the design and analysis of systems for command, control, communications and intelligence (C3I). Candidates must have earned a doctorate in engineering. Rank and salary will be commensurate with the applicant's qualifications. Research faculty and/or postdoctoral position. The research qualifications for this position are the same as those for the above described position. Interested parties should send their resume to: Chairman-Search Committee, Department of Systems Engineering, Room 330, Science and Technology II, George Mason University, Fairfax, VA 22030-4444. George Mason University is an equal opportunity/affirmative action employer.

University of Minnesota, Minneapolis, Minnesota. The Depart of Electrical Engineering invites applications and nominations for an Assistant Professor tenure track position in VLSI architecture and circuit design with application emphasis in CAD and signal and image processing. The duties of the faculty member include the establishment of a sponsored research program and teaching at both the undergraduate and graduate levels. The requirements of this position include an earned Doctorate in an appropriate discipline at the time of the appointment and outstanding academic and research records. Applications and nominations ;should be sent with a resume containing the names of three references to: Professor Larry L. Kinney, Chairman, Faculty Recruiting Committee, Department of Electrical Engineering, University of Minnesota, 200 Union Street SE, Minneapolis, MN 55455. The last date for receiving applications will be May 1, 1992, for the position available September 16, 1992. The University of Minnesota is an equal opportunity educator and employer.

The Electrical and Computer Engineering Department, University of Michigan-Dearborn has an opening for a faculty position at the Assistant/Associate Professor level starting Fall 1992. The selected candidate is expected to be active in research, and teach graduate/undergraduate courses in analog and digital electronics, microprocessor based systems design and design of VLSI circuits. The ECE department currently has active externally funded research programs in the areas of Control Systems, Computers, Image Processing and Pattern Recognition. Dearborn, a city near Detroit is the headquarters of major automobile and parts manufacturing companies and offers research opportunities in the areas of vehicular electronics, signal processing and sensor design. Send resumes to: Chairman, ECE Dept., Univ. of Michigan-Dearborn, 4901 Evergreen Road, Dbrn, MI 48128, U of M is an equal opportunity educator and employer and specifically invites and encourages applications from women and minorities.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

Academic Positions Open

The Electrical Engineering Department at Norwich University invites applications for three tenure track positions at the Assistant Professor level commencing July 1, 1992 in the following areas: (1) Power Systems and Electric Machines, (2) Communications and Signal Processing, and (3) Solid State Electronics. Appointments at a higher rank will be considered based on teaching experience. A strong commitment to undergraduate teaching is essential as is a desire to become involved in our broad-based, laboratory oriented curriculum. Ph.D. preferred but will consider M.S. with significant relevant experience. U.S. citizenship or permanent residency strongly preferred. Norwich University is located in an area of central Vermont that offers rural living with good schools and outstanding recreational opportunities. The electrical engineering faculty is located on the military college campus. Send resume and the names of three references to: Chair, Electrical Engineering Search Committee, Norwich University, Northfield, VT 05663. Norwich University is an equal opportunity employer.

Bellmon Chair in Photonics—Oklahoma State University, School of Electrical and Computer Engineering. Oklahoma State University invites nominations and applications for the Henry and Shirley Bellmon Chair in Photonics. The successful candidate will have an established reputation as a scholar, a demonstrated capacity for leadership and a sincere interest and ability to develop multi-disciplinary faculty and student programs in Photonics. The person who is selected for this position will hold a tenured position in the School of Electrical and Computer Engineering and will teach courses relating to their interests at the graduate and undergraduate levels. The person will work very closely with the faculty in the Department of Physics and will participate in the research program of the OSU Center for Laser Research. Applicants should have received an earned doctorate with at least one degree in Electrical Engineering and should have a strong background in academic and/or industrial research in the application of optical technology to problems in areas such as communications, computation or surveillance. The OSU Center for Laser Research was established in 1988 to focus optical research in a nationally prominent program with faculty from Physics, Chemistry and Electrical Engineering. A new building has recently been completed with 9,100 square feet of prime research space already occupied by the Center. Current projects being conducted by the Center are funded from the federal government, the State of Oklahoma and private industry. Oklahoma State University has made a substantial commitment to the Center and to the Henry and Shirley Bellmon Chair which is funded by an endowment of one million dollars. Nominations and applications, including a curriculum vitae should be sent to: Professor James E. Baker, Head, School of Electrical and Computer Engineering, 202 Engineering South, Oklahoma State University, Stillwater, OK 74078-0545.

Delft University of Technology (Netherlands), Faculty of Electrical Engineering announces a vacant chair in telecommunication networks. The full professor will be appointed in Telecomnmunications and Traffic-Control Systems group, where teaching and research responsibilities are shared by three chairs. Key areas of attention in this group are: tele--information systems, including data networks and mobile communications, radio location, navigation and traffic-control systems; teletraffic theory (ATM); systems integration. The successful candidate will assume network architecture, including protocols, interfaces and switching techniques, and for the systems engineering disciplines necessary for design and management of major communication infrastructures. He/she is required to have an outstanding research record and practical experience within this area. He/She should demonstrate strong didactic skills and the ability to stimulate joint research with other disciplines, in addition to directing and personally advancing the research of the chair. Send nominations or applications (including a C.V. and a list of publications) in confidence to: Prof. J. Davidse, Dean of E.E., P.O. Box 5031, 2600 GA Delft, the Netherlands, quoting vacancy No. ET9125/2731.

The EEE Department at the Hong Kong University of Science and Technology invites applications for faculty positions for Professor, Reader, Senior Lecturer and Lecturer. The Department is rapidly expanding and is expecting to double its current faculty size of 12 in 1992/93. Areas of particular interests include IC design, microelectronics, semiconductor materials & devices, microsensors, photonics, signal processing and communications. Salaries and benefits are highly competitive with those in the U.S. Initial appointments will generally be on a 3-year contract; a gratuity equal to 25% of the total basic salary drawn will be payable upon successful completion of contract. Applicants should possess a doctorate degree or equivalent with demonstrated research experience. Interested applicants should send signed resume with a statement of teaching and research interests to Professor Peter W. Cheung, Head, Department of Electrical & Electronic Engineering, HKUST, Clear Water Bay, Kowloon, Hong Kong. Applications in response to earlier advertisements will automatically be reviewed and such candidates need not re-apply.

Government/Industry Positions Open

Central Electronics Engineering Research Institute, Pilani (Rajasthan). Central Electronics Engineering Research Institute, Pilani (Rajasthan) 333031, India invites applications for senior positions from Indian Nationals, Ph.D./M.S. with proven leadership to plan and implement R&D projects in Computer and ASIC based Systems for Telecommunications, Industrial Process Control, Thin Film Materials and Equipment Development for Advanced Electronics Research. Ability to attract project support will be valued. CEERI is a leading National Laboratory conducting R&D on Electronics Systems for Industrial Automation, Microelectronics and Strategic Electronics. Send detailed resume and names and addresses of three professional references to the above address on or before July 15, 1992.

Electrical Engineer; 40 hrs/wk; 7:30 a.m.-4:00 p.m.; $31,455/yr. Performing short-circuit, load flow and coordination studies. Must have taken a course in Electrical Machinery Transient Process, Stochastic Optimal Control, and Electromagnetic Field Theory of Electrical Machinery. Must have a B.S. in Electrical Engineering and at least 1 years's experience in job offered or as Electrical Design Engineer. Must have proof of legal authority to work permanently in the United States. Send resumes to: Illinois Department of Employment Security, 401 S. State St., #3 South, Chicago, IL 60605, Attn; L. Boksa, Reference #V-IL 4364B. 2 copies of your resume required. An Employer Paid Ad, No calls.

Electrical Engineering Coordinator, Research in the design, testing, and manufacture of electronic medical products. Oversee the initial design and manufacture of electronic components produced in company's plant in Lebanon and future plant in Belgium to ensure that parts are complementary. Design electronic components of equipment, including circuits and integrated systems. Study and evaluate operational systems and recommend design modifications where appropriate. Serve as communications link with overseas plants concerning design specifications, using the French and Arabic languages. Requires B.S. or equivalent in electrical engineering, command of Arabic and French, expertise in the use of software emulators and the following computer languages: C and Assembly language. Applicants must have a working knowledge of word processing systems and the use of oscilloscopes, digital volt meters, frequency generators, and frequency counters; a background in calculus and numerical methods; and one year of work experience in electrical engineering, industrial management, or medical instrumentation engineering. Job site: Hamden, Connecticut. Salary Offered: $34,000.00 per year. Applicants Direct Resumes to: Job Service Technical Unit, Connecticut Department of Labor, 200 Folly Brook Boulevard, Wethersfield, Connecticut 06109. Refer to Job Order No. 3095284. No Calls Please.

Engineer, Senior Design. Design and develop speech and channel codec algorithms for digital cellular applications. Perform high level algorithm development, simulation and DSP coding. Design and implement error control coder and decoder. Design high performance Viterbi decoder with trade-off analysis of soft/hard decision, channel state information, and erasure scheme, utilizing C and Pascal. Req.s Ph.D. in system design or electrical engineering, with emphasis on speech signal processing, and one year of exp. in the design and development of digital cellular telephones, and speech and channel codecs, and the development and simulation of high level algorithms. Exp. must incl. the use of digital signal processing and C. $64,000/year. Job Site/Interview: Berkeley, California. Send this ad and resume to Job Number #PC 20534, P.O. 9560, Sacramento, California 95823-0560, no later than April 30th. EOE.

Position Available, Chief Scientist. Duties: directs research and development efforts including supervision of engineers and scientists in all aspects of the design and development of meteor scatter antennae systems. Responsibilities include analysis and evaluation of antennae performance, prediction of number, location and duration of meteor ionization trails and development and evaluation of prediction models and data protocol. Additional duties include assignment and coordination of research and design projects among engineers and scientists and preparation of periodic project report to management. Education: must have a Masters of Science in electrical engineering or equivalent. Experience: must have four years experience as Senior Scientist or four years experience with meteor burst communication systems. Additional requirement includes one year applied knowledge in meteor ionization modeling. Salary: $70,000 per year, exempt position, 9 to 5 in the Kent, Washington area. Please send resume by May 1, 1992 to Employment Security Department, E&T Division, Job # 299344, P.O. Box 9046, Olympia, Washington 98507-9046.

Lead Product Design Engineer. For Roan. VA area emp. to develop new excitation control of AC generators for steam, hydro and gas turbine apps. Manage apps. for oil well drilling generators. Convert and upgrade drive systems, promote joint study of power system design amongst company facilities. Consult with application engineers and customers regarding performance issues dev. methods to simulate and develop embedded digital regulator app. Must have M.S. in Elec. Eng.-motor controls w/6 yrs. wk exp. in power electronics and cont. eng. Exp. w/DC drive and excitation, computer modeling, prog. in Pascal and turbo assembler langs. & Intel 8086, PLM 86/96, TMS 320 & 80196 micro computers; synchronous machine operation, vector controlled drives and phase-lock loops. 40 hrs./wk, hrs. 8:00-4:45, $52,200.00/yr. No OT. to apply: mail or hand carry res. w/copy of ad attach to: VEC, Dept. 3008, 1202 Franklin Rd, Rke, VA 24002-0061, JO #VA1120883, EEOE.

Senior Optical Coating Engineer. Will use optical coating deposition equipment for plastic lenses, Filmcalc coating design program, SEM ("Scanning Electron Microscope"), TEM ("Transmission Electron Microscope"), and XRD ("X-ray Diffraction") to optimize the electrochromic deposition process and coating design for commercial prescription ophthalmic eye wear. Must have Master's Degree in Optical Science or Photoelectric Technology and two years of experience as Optical Coating Engineer. Prior experience must include operating knowledge of optical coating deposition equipment for plastic lenses, Filmcalc, SEM, TEM, and XRD. Must have legal right to work permanently in the U.S. This full time position pays $40,000 per year. Job site and interview in greater Portland, Ore-

CLASSIFIED EMPLOYMENT OPPORTUNITIES

gon Area. Send resume to Oregon Employment Division, Job Order No. 5550268, 875 Union Street, Salem, Oregon 97311.

Senior Installation Support Engineer—Set up, troubleshoot and demonstrate computerized numerical control (CNC) coordinate measuring machines (CMM) or logic systems. Align and troubleshoot electronic control systems using company standards. Interpret and program in CMM software languages. Set up A.C. and D.C. drives and servo control systems. Create and generate concepts and designs for the improvement of company products. Position requires travel to customer work sites throughout North America +90% of the time. Performs tasks without routine supervision or direct support. Salary, $730.00 per week, basic 40 hour week (7:30 a.m.—5:00 p.m.) overtime as needed. Requirements, 2 years of college majoring in Electronics; 2 years experience in related occupation as a Machine Fitter. Mechanical/Electrical; experience must include assembly of mechanical machine component sub assemblies and electrical wiring harnesses for CNC CMM systems. Send resumes: MESC, 7310 Woodward Ave., Rm. 415 (Ref. #0392) Detroit, MI 48202. Employer paid ad.

Electrical Engineer—Under direction of project manager will conduct research and development activities relating to development of digital signal processing algorithms, techniques and software for ground penetrating radar systems. Participates in the development of radar data acquisition system. Will use C, Fortran and low level computer language. Must have Ph.D. in Electrical and Computer Engineering and advanced level courses in Digital Signal Processing, Pattern Recognition, Digital Image Processing, and Computer Interface Design, established research ability in area of digital signal and image processing for resolution enhancement, as evidenced by publications. Five (5) days, 40 hrs/wk, $40,000/yr. Send your application, resume and three (3) letters of reference to Penetradar Corporation, P.O. Box 277, Sanborn, NY 14132.

Electronics Engr.—Conduct R&D on sat. commun. payloads w/on-board switching & signal-processing architectures. Apply stat. commun. & queuing theory to analyze/simulate perf. of sat. packet-switched netwks. Conduct R&D on mod/coding & mult. access techniques & integration of sat. dig. netwks. w/terr. netwks. Perf. system trade-off studies on ground & space segmt. reqmts. in fixed & mobile sat. commun. systems. Supervise tech. aspects of projects assigned to jr. engrs. Exp. in Fortran & C using VM/CMS & Unix oper. systems. In-depth knowl. of Intelsat & mobile ground & space segmts. Rqmts: Ph.D. in Electronics Engr. and 5 yrs. exper. as Electronics Engr. or Member of Technical Staff in the Telecommun. field. M-F; 40 hr./wk; 8:30-5:00; Sal: $74,600/yr. Mail resume & copy of ad to MD DEED, 1100 N. Eutaw St., Rm. 212, Balto., MD 21201; JO #9148822; Job Location: Clarksburg, MD.

Control Systems Engineer needed by company which manufactures and sells computers to develop functional real-time control system requirements and controls hierarchy for automation in a computer integrated manufacturing (CIM) environment. Engage in analog/digital signal processing systems design, network integration and RF interference test to assure compliance with FCC regulations. Requires BS, Electrical Engineering or related field; 2 years experience as electrical engineer involved in real-time control systems design with multivendor network architecture; and working knowledge of CIM planning a real-time computer control systems with high speed 386 computing devices and network architecture; and working knowledge of RF interference on CIM control systems. $35,000/year; 8:00am-5:00pm, M-F. Respond by resume no later than May 1, 1992 to Colorado Department of Labor & Employment, Division of Employment & Training, 600 Grant, Suite 900, Denver, CO 80203, ATT: James Shimada, and refer to Job Order No. CO3773912.

Software Systems Engineer needed by company which manufactures and sells computers to develop and test firmware, operating systems, device drivers and utility software for computer integrated manufacturing network architecture with high speed PCs, workstations, and superminicomputers. Evaluate design alternatives for system compatibility and performance, and develop hardware compatibility tests. Design simulation software, information processing software in DOS/UNIX and network environment. Requires BS, Computer Science or Computer Software Engineering; 2 years experience as software systems engineer with RF interference testing and network integration; and working knowledge of simulation software, information processing design in DOS/UNIX operating system for MC68030, 68040 architecture, 386/486 based PCs, workstations and superminicomputers. $31,900/year; 8:00am-5:00pm, M-F. Respond by resume no later than May 1, 1992 to Colorado Department of Labor & Employment, Division of Employment & Training, 600 Grant, Suite 900, Denver, CO 80203, ATT: James Shimada, and refer to Job Order No. CO3773913.

GPS Design Engineer: Principal investigator on SBIR and associated work. GPS/Spread Spectrum comm, Kalman filtering, system sim/anal. Control Systems and MATLAB. PhD or MSEE. To:85K. RF/Microwave Design Engineer: Design/Dev of RF and/or Microwave systems. Radio design DC/Ku-band, analog, RF/microwave design, frequency synthesizer design, digital radio design, antennas, and CAD/CAE. PhD or MSEE. To: 85K. Resume to: GeoSearch, Inc., PO Box 62178, Colorado Springs, CO 80920. Fax: 719-260-7389. Phone: 719-260-7087.

Engineer, Process. Resp. for designing & developing semiconductor wafer process for high density VLSI memory chips in photolithography/etch area; performing process/yield analysis using SEM/EDS; conducting rsrch & development of new etch process; analyzing etest & sort data using VAX/SUN database; technical support of the photolithography/etch area, incl. troubleshooting the photo/etch process problems & setting up CD measuring programs; & operating, troubleshooting, & maintaining all photo/etch equipment. Reqs. M.S. in E.E. Also reqs. knowl. of device physics, operation & maintenance of process equipment, SEM/EDS, & VAX/SUN under a UNIX environment. Salary: $34,271/yr. Job & intrvw site: Round Rock, TX. Apply at the Texas Employment Commission, Austin, Texas or send resumes to the Texas Employment Commission, TEC Building, Austin, Texas 78778, J.O. 6422293. Ad paid by equal employment opportunity employer.

Engineer, Design. Resp. for design & testing of high speed integrated circuits, particularly dual port memories. Duties incl. circuit design, layout design, simulation & silicon verification. Reqs. M.S. in E.E. Also reqs. knowl. of: semiconductor device physics; logic & analog circuit design using CMOS & Bipolar devices; C programming & UNIX & SUN operating systems; advanced CAD programming; & underst. of LSIM logic simulation software & M-language modeling. Salary: $820.83/wk. Job site: Starkville, MS. Send this ad & your resume to Job #2600531, Mississippi State Employment Service, 100 Felix Long Drive, Starkville, MS 39759-9983. Must have legal right to work.

Engineer, Advisory Electronic Design: Req. MSEE or MSCS and coursework or exp. in firmware for drive controller interface, functionality of disc drives, real-time programming in Assembly and C languages, PC-based ethernet networks, UNIX miniframe computer systems, logic design, computer architecture, digital system design, microprocessors, switching theory and automation, and IC applications. To develop microcode for disc controller firmware, to perform system administration and network supervision, to provide customer support on existing products and input on future hardware/software designs. $44,545/yr. Job site/interview: Minneapolis, MN. Clip ad and send with resume no later than May 5, 1992 to Mr. Dick Hewetson #1-262, MDJT, 390 N. Robert Street, St. Paul, MN 55101. EOE.

Electrical Engineer, to organize and direct consultations with potential clients concerning their needs for specialized electrical equipment. Must employ all aspects of electrical engineering principles in designing equipment according to client's specific needs. Compile research and prepare investigative reports concerning computation and electrical systems developed. Fluent in Spanish and English, 2 years experience and a B.A. Degree in Electrical Engineering required. 40 hours per week/$450.00; 10 hours overtime, $16.88 hr. Send resume to Job Service of Florida, 701 S.W. 27 Avenue, Room 15, Miami, Florida 33135. Ref. Job Order #0551058.

R&D Engineer in fiber optics for medical devices; development of devices for laser beam delivery and image transmission through multimode fibers Req. degrees in Mech. Eng., Elec. Engr. with concentration in laser optics, and PhD or completion of course-work for and admission to candidacy for PhD in biomedical engineering; 2 yrs. exp. in position offered or 3 yrs. in fiber optic research. $43k yr. Resume to Fiberguide, 1 Bay St., Stirling, NJ 07980.

Electrical Engineer—Central Ohio Mftr. Conducts research and development activities on various real time testing systems, monitoring systems, and automatic manufacturing systems; designs and develops hardware, electronic control circuits and programmable logical control software codes by using Mitsubishi, Yaskawa, and Modicon on-line computer programmers. Develops and modifies programmable logical control systems and personal computer link systems to remote control, monitor production and collect data by using C, Fortran, and QBasic computer language. Uses Laser and Charge-Coupled Devices (CCD) for on-line precise measuring of products to insure conformance with functional specifications and customer requirements; uses mechanical vibration theory and discrete-time signal processing techniques to analyze assembled products's quality. Investigates, defines all products and writes project proposals. Requires MS, Electrical or Systems Engineering. 40 hrs/wk, 8:00 a.m.—5:00 p.m.; $625/wk., no experience required. Must have proof of legal authority to work permanently in U.S. Send resume in duplicate (no calls) to G. Maugans, JO #1259262, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, Ohio 43216.

Computer Systems Specialist (Medical Imaging Research/Systems Support)—$38,861—$60,070. The Clinical Center of the National Institutes of Health is seeking a senior systems manager/scientific programmer to provide computer systems support for the Radiology and Nuclear Medicine Departments, and to assist with collaborative ventures between the Clinical Center Imaging Science Group, the Division of Computer Research and Technology, the Biomedical Engineering Branch, and the 13 Institutes. This position is part of a new Clinical Center initiative to improve the Clinical Center's in vivo imaging capabilities in order to better support the Institutes' clinical research needs. The applicant must have experience in scientific programming and some aspects of system management. Familiarity with image (medical or non-medical) analysis or display is desirable. The position combines image analysis research support with systems support of the clinical in vivo imaging analysis systems. This includes analysis, display, storage and retrieval of images from a wide variety of state of the art imaging systems. The successful applicant will support this work and the related computer infrastructure. U.S. Citizenship required. Send your Application for Federal Employment (SF-171) and Resume to: Mr. Patrick Murphy, NIH, Bldg. 10, Room 1C-660, 9000 Rockville Pike, Bethesda, MD 20892. EOE.

Government/Industry Positions Wanted

EE-Motors—AC/DC over 20 years exp. Write details to: Spectrum, Box 3-1, 345 E. 47th St., NY, NY 10017.

Legal aspects

(Continued from p. 17)

lecting to determine if the individuals were represented by counsel, by not clearly indicating that they were working for a party adverse to Monsanto, and by failing to clearly state the purpose of the interviews.

Although the court did not ban further interviews, it noted that the attorneys had a professional duty to supervise the investigators, and threatened to fine the responsible attorneys US $5000 for each subsequent interview not conducted properly.

THE ATTORNEY-CLIENT PRIVILEGE. The scope of an *ex parte* interview may be limited by the attorney-client privilege. Under the privilege, confidential discussions between corporate personnel and the corporation's attorney may be safeguarded, if certain criteria are met. If so, an outsider such as an opposing attorney cannot ask the employee to reveal what was discussed.

The impact the attorney-client privilege can have on an *ex parte* interview is vividly illustrated in a 1990 Federal case between PPG Industries Inc. and BASF Corp. PPG had developed a process for coating the exterior of aluminum cans and was advised by counsel to maintain the process as a trade secret rather than to seek patent protection.

Shortly after a PPG employee familiar with the process left to work for BASF, BASF's coatings exhibited a significant improvement. PPG believed that this could have happened only if BASF had acquired PPG's process, leading PPG to bring suit against BASF and the former employee for misappropriation of trade secrets.

Another former PPG employee—a co-inventor of the coating process—had also moved over to BASF, where he was at the time of the lawsuit. While still at PPG, however, he had been privy to discussions with PPG's counsel regarding the process.

PPG, concerned that BASF or its lawyers might attempt to interrogate the co-inventor about PPG's trade secret, requested the court to prohibit any contact, notwithstanding that he was now a BASF employee. While the court declined to grant such a sweeping order, it did rule that BASF could not inquire into any matters discussed with PPG's lawyers, as they were arguably protected by the attorney-client privilege.

WHAT SHOULD YOU DO? If the telephone rings and it is an attorney seeking information in a suit against your current or former employer, reflect carefully before replying. If you are represented by counsel in this matter, tell the attorney to contact your lawyer.

You can refuse to answer any questions, and several courts have required the attorney to inform people of this option. Nevertheless, if an attorney is intent on speaking with you, a refusal could be met with a deposition subpoena (or notice), which cannot be ignored. Since a deposition can be a long and grueling process, on balance it might be more expedient to agree to an informal interview.

Even if you are willing to answer the inquiring lawyer's every question, be aware that you may be bound by an employment agreement specifying confidentiality and proprietary rights. Thus, you may be precluded by the employment contract from voluntarily discussing certain matters.

Finally, each situation will turn largely on the facts and on the way in which the courts in your state have dealt with *ex parte* interviews. Make no mistake: this is a complex area of the law and a brief consultation with an attorney—either your company's counsel, if you feel comfortable approaching that person, or your own lawyer—could prevent trouble in the long run. To be absolutely certain, the concerned parties can apply to the court for a ruling before any statements are made, avoiding the need to stuff the genie back into the bottle.

Joel Miller is an attorney in private practice in West Orange, N.J.

COORDINATOR: Trudy E. Bell

EEs' tools & toys

'Amazing PC' exhibit opens in Boston

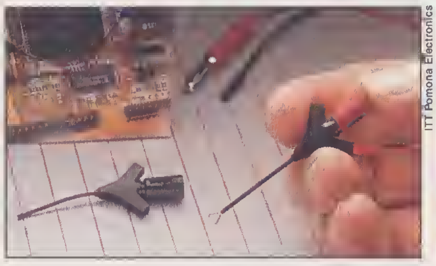
Boston's Computer Museum will soon open a new exhibit called "Tools & Toys: The Amazing Personal Computer" to add to its nearly 100 other hands-on exhibits. This exhibit will contain over 30 interactive workstations where visitors will be able to explore moviemaking, computerized music, text recognition software, and voice-activated systems, among other engaging pastimes. The opening of the exhibit on June 13 will mark the museum's 10th anniversary and will launch a year of special events to celebrate the occasion.

"Tools & Toys" will also feature public meetings to help visitors understand the rights and responsibilities of computer users, including the issues of privacy and piracy. The museum is open daily from 10 a.m. to 5 p.m., except Mondays, and every day during the summer. Admission is US $6 for adults, $5 for students and seniors, and free for museum members. *Contact: The Computer Museum, Museum Wharf, 300 Congress St., Boston, Mass. 02210; 617-426-2800; or* **circle 101.**

INSTRUMENTATION

Tight stacking

A new miniature test probe can test surface-mounted and high-density-lead devices, as well as fine-gauge wires, in extremely tight areas. The series 5790 Rotating Micrograbber, a spring-loaded pin vise, can reach into spaces as narrow as 1.2 mm with its fine-pointed pincer, and its rotating finger grips



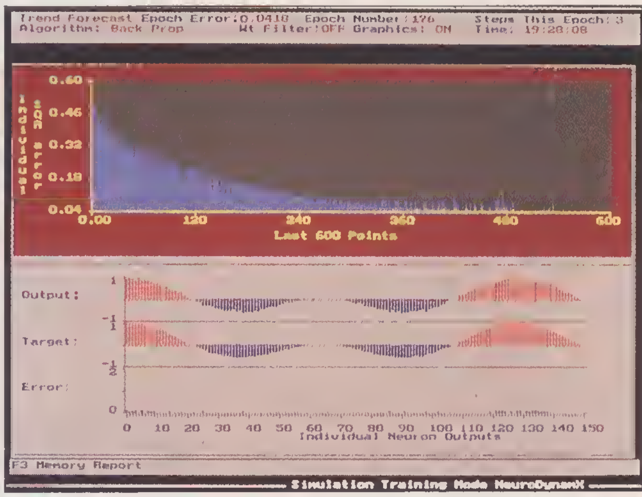
ITT Pomona Electronics

The Rotating Micrograbber can access small spaces to test surface-mounted and high-density-lead devices.

allow the user to grasp IC leads firmly. Unlike rigid test probes, the unit is flexible enough to be bent and fixed around a 35-degree angle.

The Micrograbber's 1.2-mm barrel allows for tight stacking of multiple probes, making it especially effective for use with logic analyzers, oscilloscope accessories, or any application requiring multiple, high-density connections to be tested.

The probe is rated at 42 V (2 A maximum), weighs 0.0013 kg, comes in black or red, and costs $4.60. *Contact: Customer Service, ITT Pomona Electronics, 1500 East Ninth St., Box 2767, Pomona, Calif. 91769; 714-469-2900; fax, 714-629-3317; or* **circle 103.**



NeuroDynamX Inc.

Neural networks are the key to the DynaMind 3.0 training mode screen. Trend forecast shows individual outputs in the lower window.

EDUCATION

Concurrent workflows

If your firm is looking for a cost-effective way to develop better products, you might consider attending the Eighth Annual Congress on Computer Integrated Manufacturing (CIM) Databases: Controlling Data for Concurrent Engineering. The conference, to be held April 26–28 in Cambridge, Mass., will bring together experts on information systems and data management from many manufacturing firms.

Concurrent engineering [*IEEE Spectrum*, July 1991, pp. 22–37] is a relatively new strategy used by engineering and manufacturing firms to work out manufacturing and test needs in parallel with the design of a new product. A free information kit on concurrent engineering is available. *Contact: Jacquelin Cooper, Program Director, Management Roundtable Inc., 1050 Commonwealth Ave., Suite 301, Boston, Mass. 02215; 800-338-2223; in Massachusetts, 617-232-8080; or* **circle 102.**

SOFTWARE

Neural implants

A development tool allows application programmers to embed run-time neural networks into their programs. DynaMind Developer incorporates DynaMind Version 3.0 into NeuroLink, a library of C-code routines for applications in image recognition, process control, intelligent instrumentation, signal filtering, and yield optimization, among others. Developers can use the NeuroLink routines to modularize complex problems by linking several neural networks, each dedicated to solving a portion of the overall problem.

DynaMind Developer runs on a 286, 386, or 486 PC with at least a 640K memory, DOS 3.0 or higher, and an EGA or VGA monitor. A math coprocessor and mouse are optional. NeuroLink compiles under both Borland Turbo C 2.0 and Borland C++ compilers. The package lists for $495. *Contact: NeuroDynamX Inc., Box 323, Boulder, Colo. 80306; 303-442-3539; fax, 303-442-3539; or* **circle 107.**

CONSUMER

Programmable fonts

Did you ever visualize using a special font for an application but found you couldn't because it was not stored in your font cartridge's memory? FontMaster is the first font cartridge that can be programmed with fonts not in its memory. The cartridge has a library of over 100 fonts and supports all fonts compatible with Hewlett-Packard Co. LaserJet printers.

FontMaster software comes with driver support for WordPerfect, Word, Ventura, Windows, and applications under Windows, like Postscript. Available in 1- and 2-Mbyte capacities, the units cost $449 and $599, respectively. *Contact: Kelly Computer Systems, 274 Ferguson Dr., Mountain View, Calif. 94043; 800-KCS-FONT; fax, 415-960-3474; or* **circle 104.**

COORDINATOR: George Likourezos
CONSULTANT: Paul A.T. Wolfgang, Boeing Helicopters

PROFESSIONAL CONSULTING SERVICES

THE CONSULTING GROUP

Multi-Dispciplined Engineers with P.E./Ph.D.
- Microwave, RF, Fiber-Optic Systems Design
- Oscillators, Amplifiers, Filters, Antennas, Synthesizer/PLL Design. Microprocessor, Communication ckts. Industrial Power System. R&D, Prototyping & Testing in our Lab facilities.

71-25 Austin St., Forest Hills, NY 11375
Ph. (718) 793-0777 Fax (718) 793-0770

International Compliance Corporation

Design, Test, & Consulting
- FCC Certification/Verification
- VDE, CISPR, VCCI (Japan)
- "1992" European Compliance Testing
- Product Safety: UL, CSA, IEC, VDE
- Electrostatic Discharge (ESD)
- MIL-STD 461/462, NARTE-Certified Engineers

1911 E. Jeter Rd (817) 491-3696
Argyle, TX 76226-94D1 FAX: (817)-491-3699

INTEGRATED CIRCUIT DESIGN CONSULTING

Providing integrated circuit design and analysis consulting services with gate arrays, cell libraries, or full custom in digital, analog, cmos, bipolar or ecl technologies and support services such as modeling, layout, verification, software, testing, debugging, documentation, and reverse engineering.

1556 Halford Ave, Ste 310 Santa Clara, CA 95051
(408) 243-7422

RAINES ELECTROMAGNETICS

Consulting Since 1972
- Antennas and Arrays
- Scattering and Radar Cross Sections
- Radhaz & Environmental Impact
- Simulations of Fields & Phenomena

Jeremy K. Raines, Ph.D., P.E.
President (3D1) 279-2972

IOCC

INTEGRATEO OPTICAL CIRCUIT CONSULTANTS

Consulting, Contract R&D, and Prototyping
Integrated, Fiber, and Guided-Wave Optics
- Applications Engineering
- Design, Fabrication and Evaluation
- Critical Analysis of Technology
- Troubleshooting
- Marketing

R.A. Becker, D. Sc.
President 10482 Chisholm Ave.
(408) 446-9812 Cupertino, CA 95014

O.E.M. Electronic Products
- *13 Year Product Development History*
- *Custom, RF/Digital ASICs* • *RF Systems*
- *Computerized Instrumentation*
- *Spread Spectrum Communications*
- *Finest Electronic Assemblies, Any Scale*

LocUS, Incorporated
1842 Hoffman St., Madison, WI 53704
608/244-0500 FAX 608/244-0528

CONTROL SYSTEM CONSULTING
- Servo design, high performance motion control, synthesis, system performance, simulation, specs, integration, testing
- Electrical, mechanical, hydraulic
- Defense, aerospace, industrial experience

30 East Gate Road A.R. Hazelton
Danbury, Conn. 06811 (203) 743-7002

T-TECHTM 1 DEAN ST./BDX 151 HUDSON, MASS.
VOICE: (508) 562 5820 FAX: (508) 568 1219

RF (TO 2 GHz), ANALOG, VIDEO, FIBER OPTICS, PLL'S, SYNTHESIZERS, FILTERS, A/D CONVERSION

THE MOST TIMELY, COST EFFECTIVE, AND HIGHEST PERFORMANCE SOLUTION.

Princeton Electro-Technology, Inc.

PERMANENT MAGNETS

MATERIALS, DEVICES & APPLICATIONS

CONSULTING, DESIGN, PRDTDTYPES, MARKETING

Peter Campbell, Ph.O., President
2449 Patricia Avenue **Tel: (310) 287-0375**
Los Angeles, CA 9D064 **Fax: (310) 287-0378**

IRA J. PITEL, Ph.D.

Consulting, Research and Development In Power Electronics and Magnetics

Power Supplies, Inverters, Converters, Motor Drives, Lighting Controls, Industrial Controls, Transformers, and Special Magnetics.

MAGNA-POWER ELECTRONICS, INC.
135 Route 10 Whippany, NJ 07981
(201) 428-1197

Patent Attorney

Robert E. Malm, Ph.D. (M.I.T.)
Attorney At Law

Post Office Box 522
Pacific Palisades, CA 90272
Tel: (310) 459-8728
Fax: (310) 573-1781

INDUSTRIAL CONTROLS

CUSTOM MICROPROCESSOR CONTROLS
- Machine Tool Controls
- Process Controls
- Medical Electronics
- Neural Networks
- Consumer Product Design
- Instrument Design
- Prototype Production
- Control Software

W Wintriss Engineering Corporation
4715 Viewridge, San Diego 92123
(800) 733-8089 Vic Wintriss, MSEE

NOISE, TRANSIENTS AND INTERFERENCE
- FCC, VDE, EMC/EMI
- Susceptibility, ESD, RF, Transients, Lightning
- Testing & Retrofit for Product Enhancement
- Speed to Market via Design Review
- Noise-Immune Designs and Prototypes
- FCC Compliance Training & Retrofits

TKC• THE KEENAN CORPORATION
(813) 544-2594

R. Kenneth Keenan, Ph.D.
Vice President, Engr.
8609 66th St. North
Pinellas Park, FL 34666

SOFTWARE ENGINEERING
- Real-Time Systems Analysis and Design
- Software Engineering Training (Call for Offerings)
- CASE Training and Implementation
- Consulting Services
- Product Development

Carl A. Argila, Ph.D., Inc.
SDFTWARE ENGINEERING CDNSULTANT
8D0-347-6903

Digital & Mixed Signal Designs

XILINX, PLD's, VMEbus, 680X0

"Your Place or Mine"

Jack Killingsworth Ask for
10380 131st. Street Brochure
Largo, FL 34644 (813) 596-1990

Infolytica Corp. (514) 849-8752

*Expert electromagnetics design & analysis using **MagNet 2D** and **3D** FEA software.*
- *motors*
- *transformers*
- *actuators*
- *levitators*
- *CRT design*
- *magnetizing fixtures*
- *recording heads*
- *NMR applications*
- *magnetic bearings*
- *etc. . .*

1140 deMaisonneuve, Suite 1160 Montreal, Canada, H3A 1M8

ELECTROMAGNETIC DESIGN ANALYSIS

Consultancy by world leaders in 3D electromagnetic computation using PE2D, OPERA, TOSCA and ELEKTRA
- electrical machines
- recording heads
- actuators
- transformers
- loudspeakers
- MRI scanners
- magnetic casting
- scientific apparatus
- NDT equipment
- accelerator magnets

VECTOR FIELDS INC. tel: (708) 851-1734
1700 N Farnsworth Ave, Aurora IL 60505 fax: (708) 851-2106

MICRO RESEARCH Co., Ltd

We are the top professional of
- **Microcomputer 8ased Product development**
- **Hardware/Software development**
- **Semi-custom IC development** ***-MCU, ASIC, ROM, Voice /Sound/ Melody IC***
- **End Product development**

Please Contact:
4111-15 H.K. Plaza
369 Des Voeux Rd,
West, Hong Kong
Fax: (852) 858-2693
Tel: (852) 559-3031
Telex: 74773 MICOR HX

LEONARD R. KAHN, P.E.

Consultant in Communications and Electronics
Single Sideband and Frequency Shift Systems
Diversify Reception - Stereophonic Systems
Modulation Systems
Registered Patent Agent

222 Westbury Ave.
Carle Place, NY 11514
516-222-2221

CONSULTING & PROTOTYPES

ELECTRIC MOTORS

BRUSHLESS MDTORS SWITCHED RELUCTANCE
STEPPING MOTORS AC INDUCTIDN

MAGNA PHYSICS CORP. JAMES R. HENDERSHOT
100 Homestead Ave. TEL: 513-393-9835
P.D. Box 78 513-393-3810
HILLSBORO, OH 45133 FAX: 513-393-9836

TECHNICAL WITTS, INC.

Switchmode Power Supply Design
Software Engineering – Windows, C, C++

6319 W. Villa Theresa Drive, Glendale, AZ 85308
Voice: (602) 439-1833 FAX: (602) 547-1123

Editorial Offices: New York City 212-705-7555 San Francisco 415-282-3608 Washington, DC 202-544-3790

EDITORIAL CORRESPONDENCE. IEEE Spectrum, 345 East 47th St., New York, N.Y. 10017, Attn: Editorial Dept. Responsibility for the substance of articles published rests upon the authors, not the IEEE or its members. Letters to the editor may be excerpted for publication.

ADVERTISING CORRESPONDENCE. IEEE Spectrum, 345 East 47th St., New York, N.Y. 10017, Attn: Advertising Dept. 212-705-7760. Also see Advertising Sales Offices listing on last page. The publisher reserves the right to reject any advertising.

GENERAL INQUIRIES: 1-800-678-IEEE; Headquarters: 345 East 47th St., New York, N.Y. 10017, 212-705-7900. *Tel. extensions at headquarters:* General Manager, 7910; Public Relations, 7369; Publishing Services, 7560. *At other locations:* Regional Activities, Section Services, Educational Activities, 908-981-0060 or write to IEEE Service Center, Box 1331, Piscataway, N.J. 08855; Membership Services, 908-981-0060; Professional Services, 202-785-0017; Technical Activities, 908-562-3900.

Scanning
The Institute

Medal of Honor to Amos E. Joel Jr.

A pioneer in the development of electronic switching systems, Amos Edward Joel Jr., has received the IEEE's 1992 Medal of Honor "for fundamental contributions to and leadership in telecommunications switching systems." Joel spent his entire career from 1940 through early 1983 with Bell Telephone Laboratories. He is now a consultant.

Multimedia workstations

The technical world's longest-running video conference series inaugurated its 10th anniversary season last month with the first of six IEEE conferences scheduled for this year. The next conference, on April 30, will be on the multimedia workstation of the very near future. These are workstations that incorporate sound, pictures, animation, and full-motion video with traditional text and graphics.

The conference will discuss the hardware and software tools for building these workstations, as well as their application to engineering problems. Also addressed will be the problems involved in making a transition from today's work environment of stand-alone PC users to one of collaborative workgroups requiring networked systems with more computational power and input/output rates.

Taking part in the discussion will be Gary B. Eichorn, general manager, Hewlett-Packard Co.; Steven R. Lehrman, director, MIT Center for Educational Computing Initiatives; and Andrew Lippman, associate director, MIT Media Laboratory.

The program will be broadcast from 12 noon to 3 p.m. EST through an interactive network (one-way video, two-way audio). Fees are US $1800 for corporations, $850 for universities. Contact Judy Brady, marketing manager-videoconferences, IEEE Marketing Department, 908-562-3991; fax, 908-981-8062.

Focusing on standards

To focus national attention on the importance of standards, IEEE United States Activities is joining with two dozen corporations, trade associations, and professional groups to offer a $2500 prize for the best paper on the theme: "Standards Promote Competitiveness." The group is also sponsoring National Standards Week, which will be held Oct. 11–17, when the winning author or authors will be announced.

Promoting competitiveness by applying standardization practices can be addressed from a number of perspectives: how to enhance a company's position in global markets; how to improve productivity; how to shorten development time; and how to introduce new competitive products to market.

Papers must be between 2500 and 4500 words and not exceed 20 pages, including illustrations. They must be original and not previously published. The competition is open to those working in facilities in the United States.

For rules and an entry form, contact National Standards Week Paper Competition, Standards Engineering Society, Box 21307, Dayton, Ohio 45401-2307. Entries must be received no later than June 15.

Coming
in Spectrum

OPEN SYSTEM SOFTWARE. If high-speed links are to interconnect local-area networks belonging to assorted organizations, software will be needed that can deal with equipment from many vendors.

CCD NIGHT VISION. Video signal processors incorporating charge-coupled devices (CCDs) sensitive to infrared light should further simplify, ruggedize, and enhance the performance of nighttime-viewing systems.

TESTING ASICs. Application-specific ICs (ASICs) should help speed a product to market, but ASIC testing procedures have hampered the ICs' timely delivery. Now new technologies and standards are making testing faster, more accurate, and easier.

3-V ICs. The move to submicrometer chip geometries and the rise of battery-operated equipment are encouraging the development of ICs with a low operating voltage of 3 V.

AFTER THE FLOOD. After fire, flood, or other catastrophes, companies with a sound disaster recovery plan can hope to reclaim seemingly damaged electronic systems and products for a fraction of the cost of replacing them.

WOMAN'S WORK. Elizabeth Laverick's contributions to military and commercial radar earned her top management positions in some top UK companies. Newly retired, she is eager to woo more women into scientific and engineering careers.

NOKIA'S FORESIGHT. Nokia Corp., once involved mainly in wood products, is now Europe's third largest maker of TV sets and a rising star in mobile phones and telecommunications. How does the company do it all from tiny, out-of-the-way Finland?

ADVERTISING SALES OFFICES

345 East 47th Street, New York, N.Y. 10017

William R. Saunders	Advertising Director	705-7767
Michael Triunfo	Northeastern Manager	705-7312
Hendrik Prins	Research Manager	705-7067
Theresa Fitzpatrick	Advertising Production Manager	705-7579

Boston, Mass.–Gerard S. Mullin, Doug Long, The Channel, Brewster, 02631 508-896-5930

Philadelphia, Pa.–Daniel P. Mainieri Jr., Regional Manager, 650 N. Cannon Ave. #22, Lansdale, 19446 215-368-8232

Chicago, Ill.–Ralph Bergen, One Northfield Plaza, Suite 300, Northfield, 60093 708-446-1444

San Francisco, Calif.–Denis F. Duffy, 3755 Balboa Street, Suite 201, 94121 415-386-5202

Los Angeles, Calif.–Lynne Andrew Evans, 5777 West Century Boulevard, #635, 90045 310-649-3800

Atlanta, Ga.–H. Michael Coleman, C. William Bentz III 4651 Roswell Road N.E., 30342 404-256-3800

Dallas, Texas–Matt Kincaid, 9794 Forest Lane, Suite 634, 75243 214-553-9896

Tokyo, Japan–German Tajiri IMI Corp., Saito Lend Bldg., 13-5, Ginza 3-chome, Chuo-ku, Tokyo 104. (03) 3546-2231. TELEX: J23449 (IMI TOKYO)

Munich, Germany–Ric Bessford, Leopoldstr. 52, 8000 Munich 40, Germany, 49-89-39-00-55

Publisher: Donald Christiansen
Administrative Assistant: Nancy T. Hantman
Associate Publisher: William R. Saunders (Advertising)
Administrative Assistant: Carmen Cruz
Vice President, Publications: James T. Cain

ADVERTISERS INDEX

Circle numbers on the Reader Service Card, opposite page 76, that correspond to the advertisers listed below. * Advertiser in North American edition.